Stationary Steam Engines

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STEAM VALVE
and CYLINDER
LUBRICATION

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STATIONARY STEAM ENGINES

STEAM VALVE AND CYLINDER LUBRICATION

PART I. Introduction; Construction; Factors of Steam Engine Operation; Operation; Lubrication; Selection of Oil.

PART II. Boiler Plant and Steam Production; Steam; Exhaust Steam; Oil in Exhaust Steam; Extraction of Oil; Feed Water Treatment.

INTRODUCTION

The steam engine, as its name implies, employs steam for producing power.

Reciprocating steam engines are the most reliable and highly developed and specialized of all power producers.

During the past fifteen years turbines and internal combustion engines have been introduced, so that the reciprocating steam engine no longer monopolizes the entire field.

Large steam turbines, usually units above 1,000 H. P., have, to a great extent, replaced reciprocating steam engines in central power stations and isolated power plants, in which reciprocating steam engines, formerly employed, are frequently retained as standby units. Small steam turbines, usually below 50 H. P. in size, have quite generally replaced small reciprocating steam engines as auxiliary power units for driving centrifugal pumps, fans, exciter sets, etc.

Internal combustion engines in the form of gas, gasoline, kerosene, and fuel oil engines, have been adopted as power producers in stationary plants where the difference in the cost of fuel is sufficiently favorable to warrant their installation.

Apart from the fields occupied by the steam turbine and the internal combustion engine, the reciprocating steam engine is the most extensively used power producer.

The efficiency of any reciprocating steam engine is highest when the maximum expansive value of the steam is secured.

Every precaution must be taken to prevent loss of steam heat (expansive force) and it must be used automatically, quickly, and in minimum volume, dependent upon the power requirements.

Steam cylinders are surrounded with heat-insulating material, held in position by an outer covering, generally of sheet steel; they are usually enclosed at both ends by cylinder covers.

The regulated, automatic action of the steam valves controls the admission of the required steam volume per engine stroke.

Power from the engine may be transmitted by means of a rope or belt from the engine pulley or flywheel to shafting. An electric generator, or a centrifugal pump may be operated by "direct drive," *i.e.*, coupled direct to an extension of the main engine shaft.

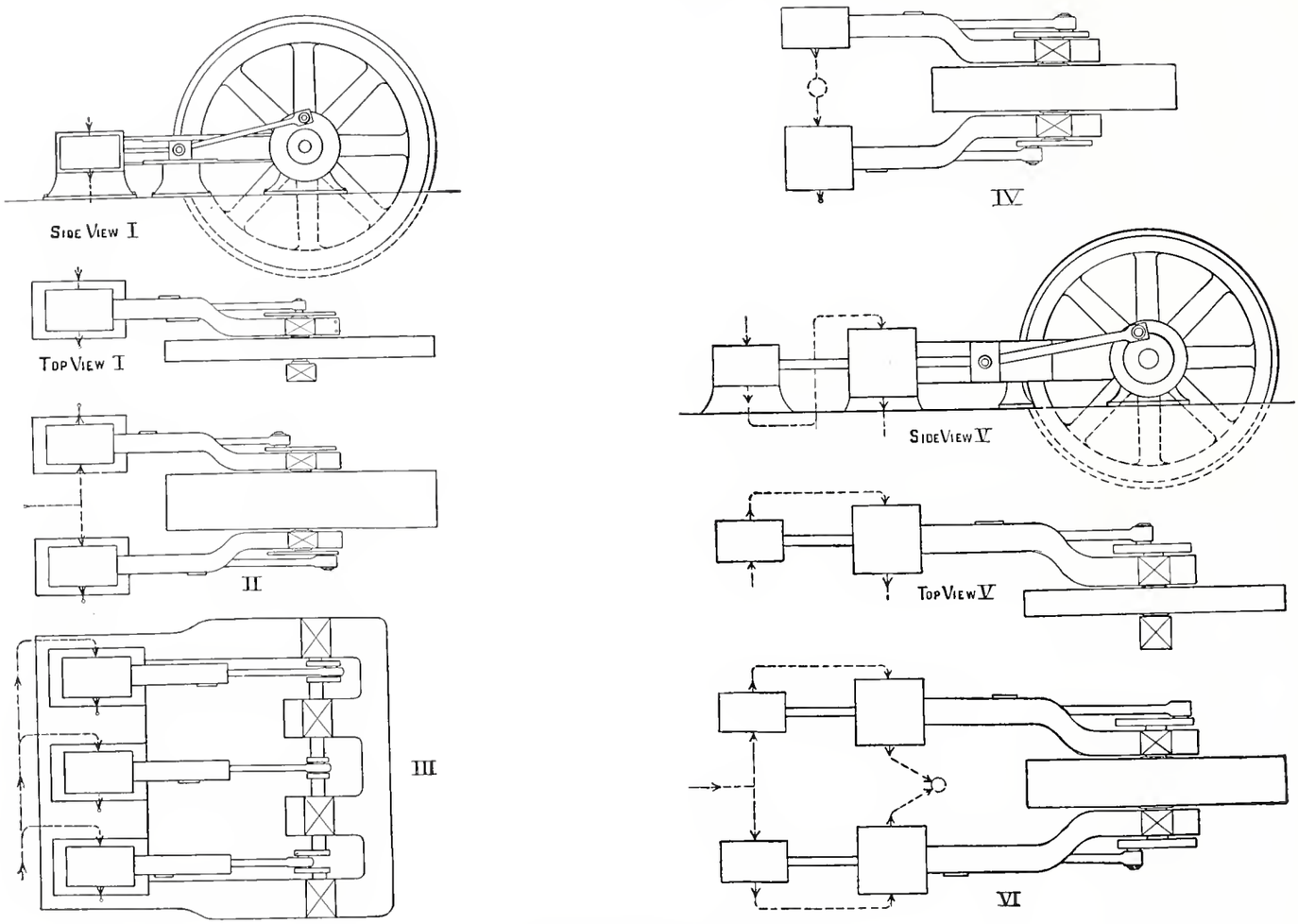

Fig. 1—Cylinder Arrangement

CONSTRUCTION

The simple engine consists of a cast-iron cylinder and valve chamber, within which are movable piston and valves respectively. A cast-iron frame bolted to the cylinder supports the external moving parts, namely, the cross-head, connecting rod, crank shaft, and fly-wheel.

Steam engines are of horizontal and vertical construction and of single and multiple cylinder arrangement.

Horizontal and Vertical Reciprocating Steam Engines

A horizontal engine is one with the cylinders placed in a horizontal position at the same level as the crank shaft.

A vertical engine is one with the cylinders placed directly above or below the crank shaft. Practically all vertical engines have the cylinders above the crank shaft. The arrangement of cylinders below the crank shaft is antiquated, although in large, slow-speed pumping engines this type still survives.

Horizontal engines are more extensively used than vertical engines.

Single and Multiple Cylinder Arrangement (Fig. 1)

Simple engines: In the early days engines were built with only one cylinder, the steam expanding or doing all its work in one cylinder.

The single-cylinder engine may be either of the horizontal or vertical type, as illustrated diagrammatically in Nos. (I) and (A) showing side and top view of a horizontal engine, and side and front view of a vertical engine respectively.

No. (II) illustrates a top view of a two-cylinder engine with cylinders placed side by side and operating the same crank shaft. This is called a twin-cylinder horizontal engine and has been developed especially as a hoisting engine.

No. (III) illustrates a top view of a three-cylinder engine with cylinders placed side by side, operating the same crank shaft. The cranks are 120° apart. This is called a triple-cylinder horizontal engine and is chiefly used in steel works as a rolling-mill engine. The severe, inter-

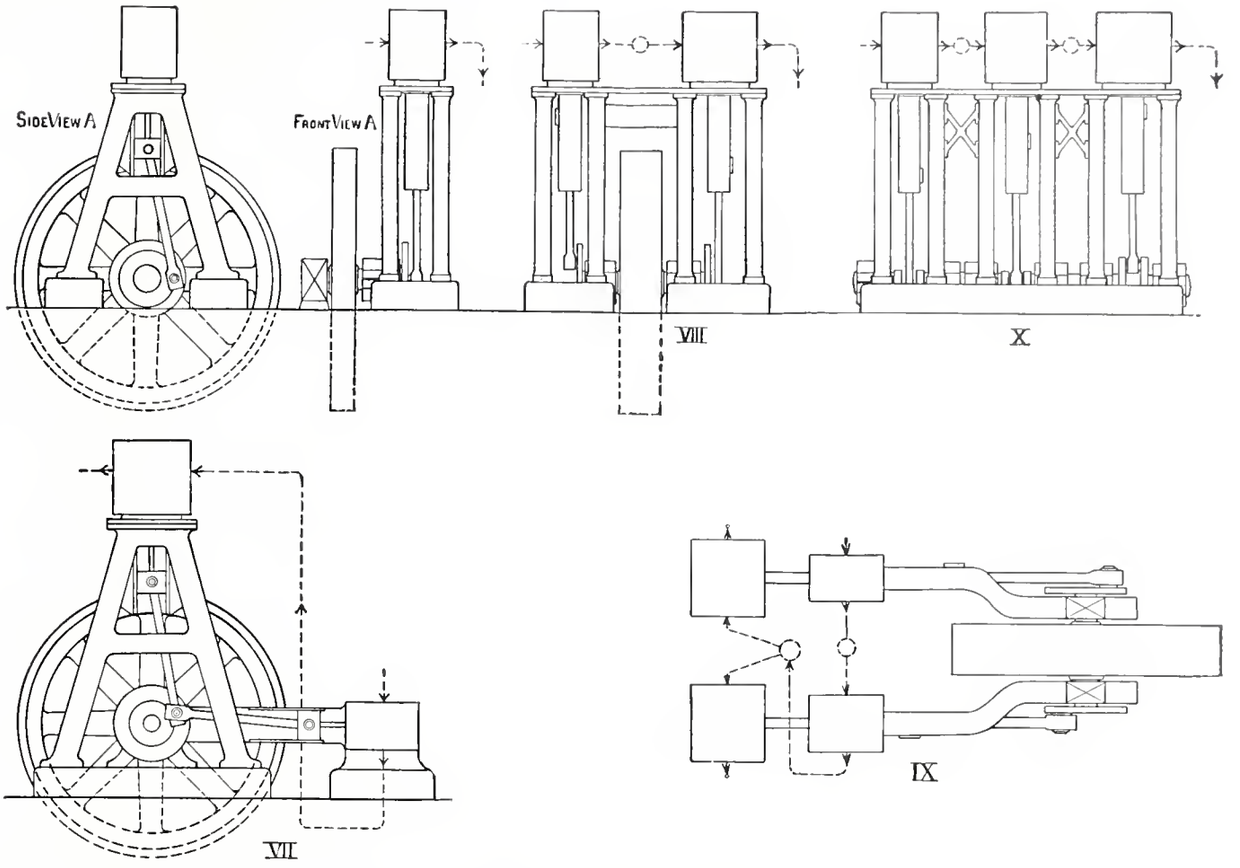

Fig. 1 Continued—Cylinder Arrangement

mittent work of these engines makes the use of a fly-wheel unnecessary.

Compound engines: An engine having a high-pressure cylinder and a larger low-pressure cylinder is called a compound engine.

By allowing the steam to do a part of its work in one cylinder—called the high-pressure cylinder, and thereafter to complete its work in a second and larger cylinder—called the low-pressure cylinder, the steam expansion in each cylinder producing equal power, more work is developed with the same amount of steam.

The arrangement of cylinders of compound engines follows:

No. (IV) top view, cylinders arranged side by side—a cross compound horizontal engine.

No. (V) a side and top view, cylinders arranged one behind the other—a tandem compound horizontal engine.

No. (VI) top view, a twin tandem compound horizontal engine.

No. (VII) side view of a horizontal high-pressure and a vertical low-pressure cylinder—an angle compound engine.

No. (VIII) front view, cylinders arranged side by side—a cross compound vertical engine.

Triple-expansion engine: A triple-expansion engine is one in which the expansion of steam is effected in three stages, by successive cylinders, known as high-pressure, intermediate-pressure, and low-pressure cylinders.

Triple-expansion engines of horizontal construction sometimes employ two low-pressure cylinders, the exhaust steam from the intermediate cylinder being distributed equally between the two low-pressure cylinders.

No. (IX) top view cylinder arrangement, similar to a combination of a cross compound and a tandem compound engine, a horizontal triple-expansion engine with two low-pressure cylinders.

In the vertical construction there is usually only one low-pressure cylinder.

No. (X) front view of cylinders arranged side by side—a triple-expansion vertical engine, generally used as a pumping engine.

The reciprocating steam engines referred to in this paper are double-acting, *i.e.*, steam expansion takes place alternately on both sides of the piston.

Single-acting steam engines employ steam expansion only on one side of the piston. (See Westinghouse Crank Case Steam Engine Paper.)

FACTORS OF STEAM ENGINE OPERATION

The following tables show the principal factors influencing steam engine operation, including the different types of valves, by which engines are sometimes classified; the most suitable range of steam pressures employed; the usual superheated steam temperatures at the pressures carried; range of engine speeds in revolutions per minute (R. P. M.), and the horse-power (H. P.) per cylinder in horizontal and vertical engines.

TABLE I

Valves	Steam Pressure Pounds per Sq. In.	Total Steam Temp. Degrees Fahr.	R.P.M.	H P. Per Cyl.
Slide	60 to 120	450	350 to 60	Up to 125
Corliss	80 to 160	525	150 to 60	125 to 2000
Piston	90 to 220	600	500 to 90	Up to 3000
Poppet (or drop)	120 to 220	600	180 to 80	125 to 3000

Valves

Valves are used for opening and closing passageways, permitting steam to enter the cylinder and to escape therefrom after it has performed its work.

The types of steam valves in use may be divided into four groups, as follows:

Slide
Corliss
Piston
Poppet

Slide Valve (Fig. 3)

The slide valve was the earliest form of valve employed, being generally adopted for use on small and medium-size steam engines. Its use results in the development of power at a high rate of steam consumption. This is due to the construction and the method of controlling the operation of this type of valve which does not permit of the economy in handling steam which can be attained with other types of valves.

Slide valves are of cast iron, built in different shapes. Their principle of operation may be likened to the service of a sliding-door.

Fig. 3, in phantom view, illustrates a slide valve (H), box-like in shape, lying upon the valve seat (H5) within the enclosed chamber or steam chest (A3). The valve (H) moves over the valve seat (H5) on the cylinder casting and the steam pressure holds the valve snugly against its seat. The valve seat has been machined and scraped to present a perfectly smooth surface, in which are openings or ports (1H2) and (2H2) communicating with the ends of the cylinder, and (H4) the large central opening for the discharge of the exhaust steam.

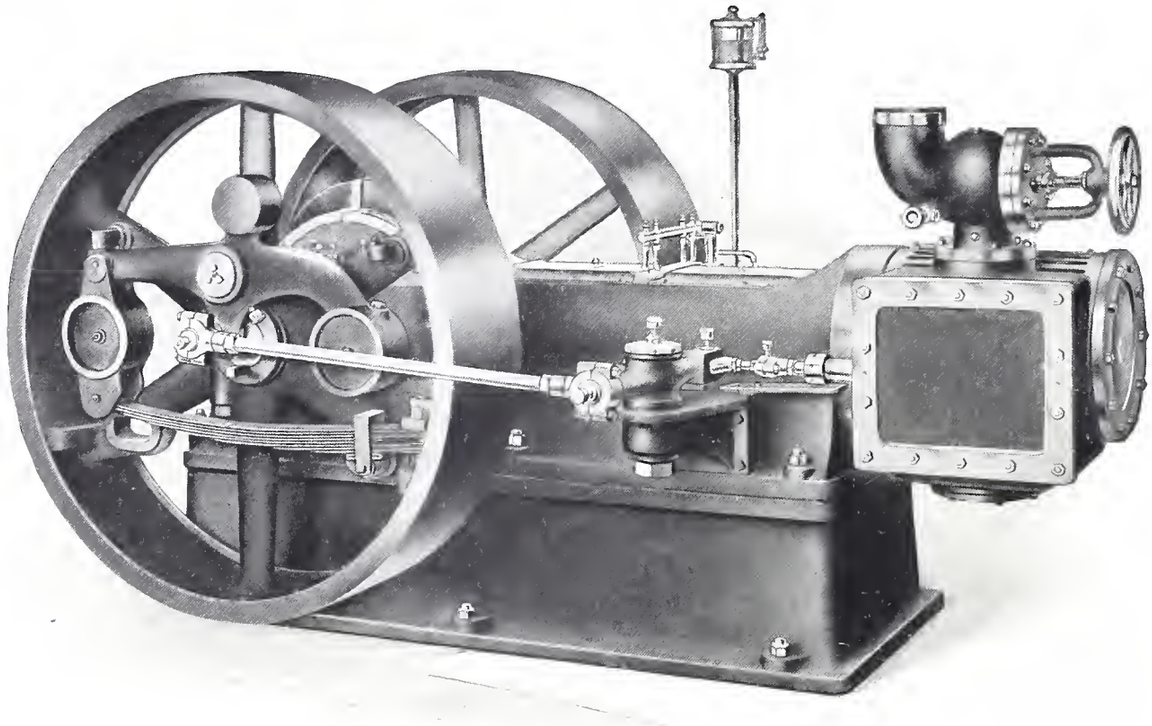

Fig. 2—Photograph of Small Slide Valve Steam Engine

The steam chest generally forms part of the steam engine cylinder casting, thus permitting short steam passages between the steam chest and the steam cylinder.

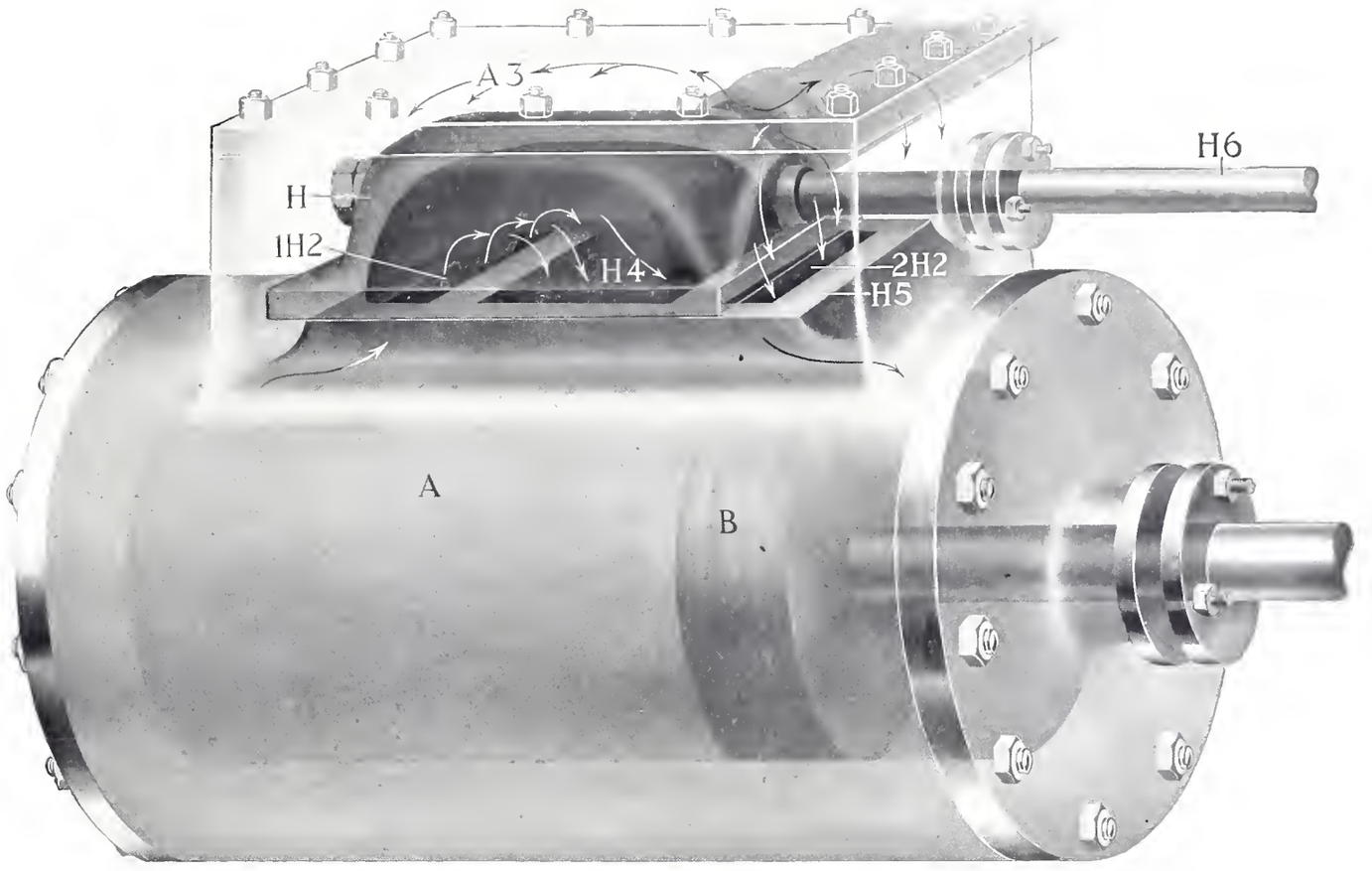

Fig. 3—Phantom View of Cylinder and Valve of Slide Valve Steam Engine

The slide valve (H) is bolted to the end of a valve rod (H6), the other end of which is connected to an eccentric rod (not shown) which is actuated by an eccentric on the moving engine shaft. Thus the valve (H) is driven endways parallel to the motion of the piston, but in an opposite direction.

As the steam passages (1H2) and (2H2) are alternately uncovered by the ends of the valve (H), steam is permitted to pass from the steam chest (A_3) into the cylinder (A). The resulting steam expansion pushes the piston (B) to and fro in the cylinder.

When steam passes into the cylinder (A) through passage (2H2) the piston (B) is pushed to the left. The exhaust steam on the left-hand side of the piston (B) is forced out through passage (1H2), the hollow slide valve (H) and the large central opening (H_4) communicating with the exhaust pipe (not shown).

When steam passes into the cylinder (A) through passage (1H2) the piston (B) is pushed to the right. The exhaust steam on the right-hand side of the piston is forced out through passage (2H2), the valve (H) and the large central opening (H_4).

Corliss Valve and Valve Gear (Fig. 4)

The Corliss type of valve has been employed for a number of years and is at present in use on the majority of large steam engines.

The construction of this type of valve and the method by which it is operated result in the very economical use of steam.

Corliss valves are relatively long cast-iron cylinders of small diameter, usually located at the four corners of the cylinder casting.

In its simplest form the central section of the valve is cut away to such an extent that less than one-half of the metal remains.

The cylindrical ends (K) of the valves constitute the supporting bearing surfaces.

The steam used is controlled by two steam and two exhaust valves.

Steam valve (1H) is shown in closed position, and (2H) is shown in opened position.

Exhaust valve (1H1) is open, and (2H1) is closed.

Valve stems (H7) having T-shaped ends are fitted into slots provided in one end of each valve. The valve stems (H7) are supported in brackets (H8) bolted on the front of the cylinder (A).

The cylinder head has been removed, exposing steam and exhaust passageways (H2 and H3) respectively, and the cylinder wall (A).

The wrist plate (H10) is given a semi-rotary motion by means of the eccentric rod (H11) and the eccentric (not shown) located on the engine crank shaft.

Valve rod (H6*b*) connects the wrist plate (H10) with the exhaust-valve arm (H9*b*). The valve arm (H9*b*) keyed to the outer end of the exhaust-valve stem (H7) thus gives the exhaust valve (1H1) a turning motion through a small arc, opening and closing the exhaust passageway (H3), permitting the exit of the exhaust steam from the cylinder (A) to the exhaust-steam pipe (A5).

Exhaust valves are thus positively opened and closed.

Mounted on each of the valve stems (H7) of the steam valves (1H and 2H) are three sets of arms.

The arm (H9) is keyed to the valve stem (H7) at its outer end. To this arm is connected the dash-pot rod (H12).

The arm (H15) connected to the governor rod (H4) is free to move on the valve stem (H7).

The bell crank (H16) is also free to move on the valve stem (H7). It is connected to the wrist plate by means of the valve rod (H6). A hook or latch (H5) on the other arm of the bell crank (H16) is in position to engage a latch plate (H17) on the arm (H9).

Through the motion of the wrist plate (H10) the hook (H5) engages the latch plate (H17), lifting the arm (H9) and opening the valve (1H). The latch (H5) is automatically disconnected

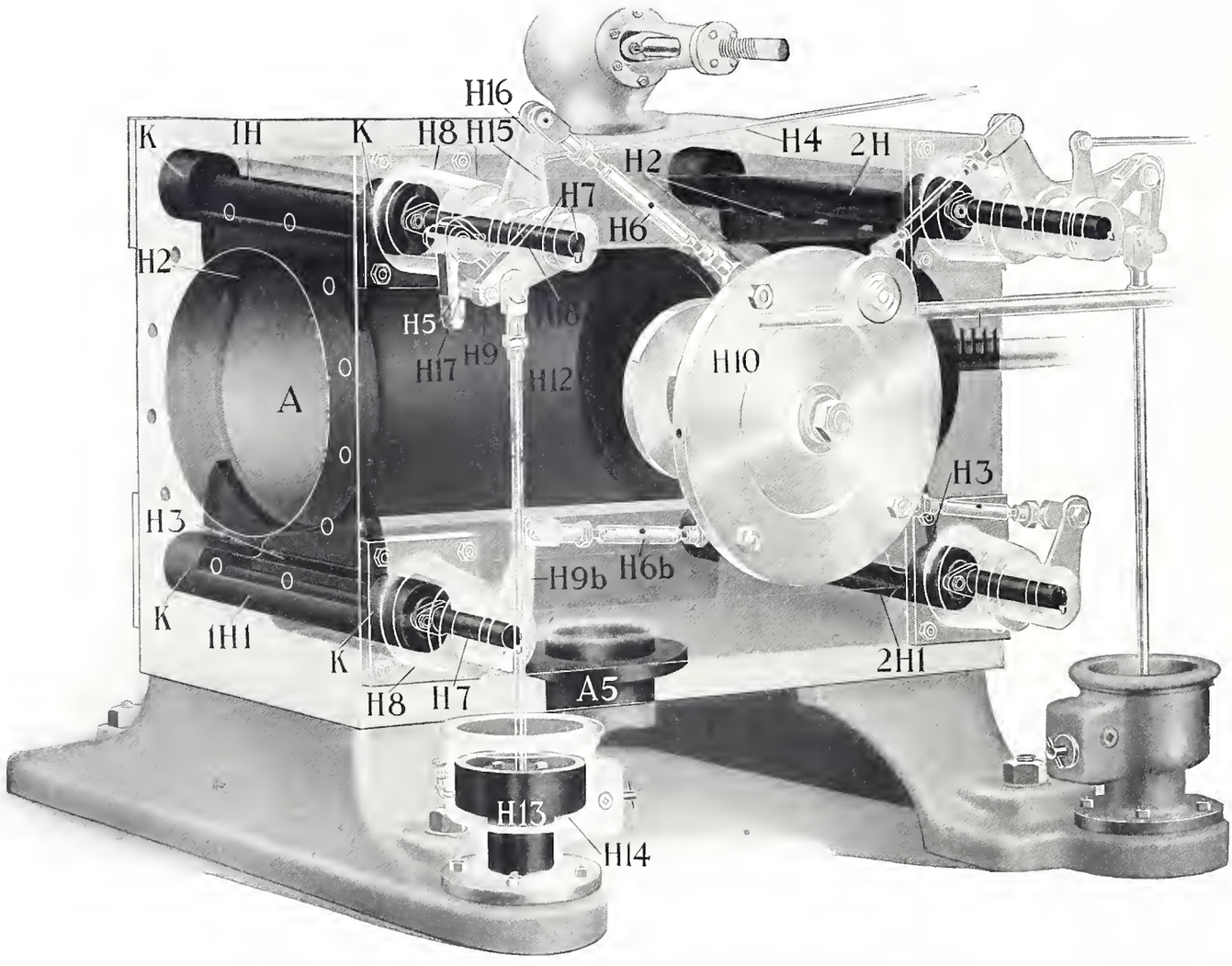

Fig. 4—Phantom View of Cylinder and Valves of Corliss Valve Steam Engine

when its back end strikes the cam (H18) on the arm (H15), the position of which is determined by the action of the governor and the governor rod (H4).

As the dash-pot piston (H13) is pulled away from the closed end of the dash pot (H14) by the dash-pot rod (H12) during the opening of the steam valve (1H), a vacuum is created in the dash pot. When the steam valve is unlatched, the vacuum created in the dash pot quickly pulls down the arm (H9), closing the steam valve (1H).

The steam valve is positively opened by the motion of the wrist plate, unlatched by the governor cam, and closed by the dash pot.

ends, which register with openings of short passageways (1H2) and (2H2) to the ends of the cylinder (A).

The principle of operation of the piston valve is similar to that of the slide valve. In practice, higher steam efficiency is secured by admitting steam through the central section of the valve (H) and permitting steam to exhaust at the ends of the valve—thereby, to a degree, preventing steam radiation losses.

When the moving piston valve (H) uncovers the slots (H7) in the sleeve (H5), steam from the steam chest (A3) enters the passageway (1H2). Exhaust steam in the cylinder (A) on the other

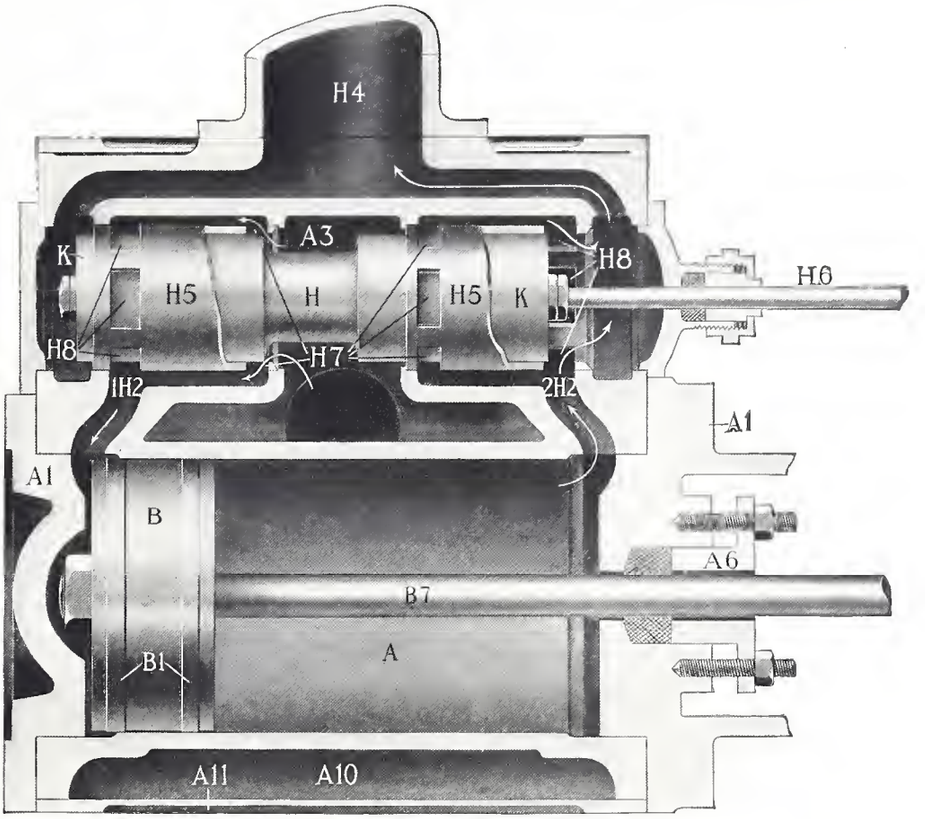

Fig. 5—Part Sectional View of Cylinder and Valve of Piston Valve Steam Engine

Piston Valve (Fig. 5)

The piston valve is of such construction and design that it can be efficiently used with the highest steam temperatures. It is not considered as economical from the point of view of steam consumption as the Corliss valve.

The piston valve (H) (Fig. 5) is a cylindrical cast-iron piston, the ends (K) having a greater diameter than the central section. The valve slides or moves endways within sleeves (H5) fixed in position in the steam chest. The walls of the sleeve (H5) are pierced with slots (H8) at the outer ends and slots (H7) at the inner

side of the piston (B) is permitted to escape through passageway (2H2), the slots (H8) in the sleeve (H5), and around the end of the valve into the exhaust pipe (H4). The position of the valve thus controls the passage of steam into and from the cylinder.

The piston valve is moved by means of a valve rod (H6) actuated by a cam or eccentric on the engine shaft (not shown).

The piston valve is automatically moved almost in step with the piston itself, being but slightly ahead of it in its motion at all times.

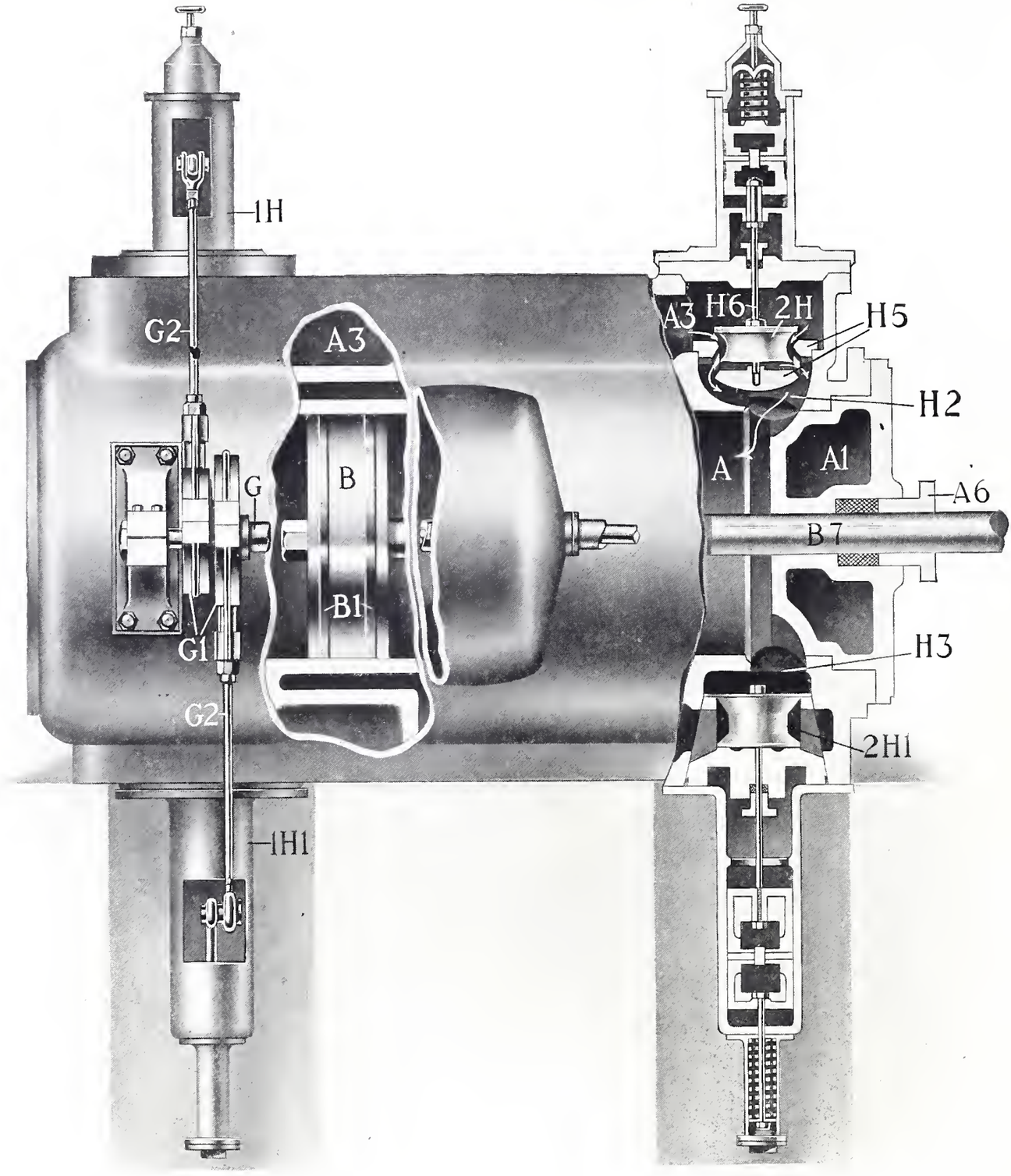

Fig. 6—Side View of the Cylinder of the Poppet Valve Engine. Cylinder Cut Away Showing Piston and the Valves at the Crank End

Poppet Valve (Fig. 6)

The poppet or drop valve is the latest form of steam valve adopted. It can be operated with high steam temperatures and at high engine speed. By its use power may be developed with very economical steam consumption.

The steam used is controlled by two steam and two exhaust valves for each cylinder.

The poppet valve is a cast-iron disc or cylindrical body (2H) fitted on the end of a long valve stem (H6). This valve may be given the shape of a drum or piston with an opening

through its axial center. The top of the valve (2H) is designed to fit an upper valve seat (H5), the other end resting on another valve seat (H5).

Valve chambers communicate through passageways with the ends of the steam cylinder (A).

The poppet valve is lifted from its seat by a lever, valve rod (G2) and cam or eccentric (G1) actuated by a revolving cam shaft (G) geared to the crank shaft (not shown). The opening of the valve is secured with a very short lift. A stiff spring in the valve bonnet forces the valve down to its closed position.

The control of steam is automatically secured by timing the opening of the respective steam and exhaust valves.

Steam Pressure

The range of pressure usually employed for each class of engine, according to its type of valve, is given in Table I, page 6.

Table II shows corresponding temperature of steam at various pressures.

TABLE II

Pressure and Corresponding Temperature of Saturated (Dry) Steam

Gauge Pressure Lbs. Per Sq. In.	Temperature ° F.
80	324
100	338
120	350
140	360
160	370
180	379
200	388
220	396

Steam Temperature

In some modern steam plants it is the practice to reheat steam above that temperature normally due to its pressure. The steam is then called superheated steam.

The figures in Table I represent the average maximum steam temperature at the engine stop valve when superheated steam is employed. The steam temperature is lower here than at the superheater. The drop may amount to as much as 5° F. for every 10 feet of steam piping if the pipes are not well covered.

The object in superheating steam is to secure greatest steam expansive force as well as to minimize condensation in the engine. Thereby higher efficiency is obtained than it is possible to secure by employing saturated steam.

Steam at very high temperature causes warping due to the irregular expansion of the valves, which are thin or unsymmetrical in shape. The effect of the high temperature on the valves and cylinders limits the degree of superheat that can be employed.

Therefore, as indicated in Table I, *slide valves can not be used with high temperature steam; Corliss valves can be used with a moderate degree of superheat; piston and poppet valves are used under the most severe conditions of superheat.*

Revolutions per Minute

Small engines frequently operate at high speed. Large engines usually operate at low or moderate speeds. Therefore, in Table I the high figures refer to the speed of smaller engines, and the lower figures to the speed of larger engines.

Engines employing the slide and piston valves run at very much higher speeds than those employing Corliss and poppet valves; this is because of the positive operation of the slide and piston valves.

Horsepower per Cylinder

The slide valve is not generally used in single-cylinder engines of over 125 H.P., because of its low steam efficiency.

The Corliss valve is employed for large steam engines. It is rarely used in engines below 125 H.P. in size, as the indirect valve action is not adaptable to the high speeds at which small engines operate.

Piston valves are used for small units and sometimes for very large power units, as they can be operated at very high speed at high steam pressure and temperature.

Poppet valves are used for the highest power units on account of their great efficiency. They are not used for power units below 125 H.P., for the same reason as given under Corliss engines.

The slide and piston valve engines are built both as horizontal and vertical engines. The Corliss valve engines are mostly horizontal engines, except in large sizes, when they may be of vertical construction. The poppet valve engines are practically all horizontal engines.

The cylinder arrangement of the engine, its vertical or horizontal construction, and the factors influencing its efficient performance have been fully outlined. The operation of the several types of steam engines follows:

OPERATION

Slide and Piston Valve Engines

As has been stated, the slide valve moves on a flat surface, and the piston valve moves in a cylindrical sleeve.

The operation of the piston valve is similar to the operation of the slide valve. The description of the operation of a slide valve engine therefore will explain the principle of operation of the piston valve engine.

An eccentric (G1) (Fig. 7) mounted on the crank shaft (F) gives reciprocating motion to the valve rod (H6) through the eccentric rod (G3) which engages the valve rod (H6) at its outer end.

The slide valve (H) within the steam chest (A3) is fixed to the inner end of the valve rod (H6). The valve motion is automatically timed to the piston motion, and through the opened passages or ports (1H2) and (2H2) steam in the steam chest (A3) passes into the cylinder (A) and from the cylinder into the exhaust pipe (H4) after it has done its work.

With the piston (B) in the position at the left, the slide valve (H) permits live steam to pass through the passage (1H2) into the cylinder between the cylinder cover (A1) and the piston (B).

The steam expansion forces the piston (B) away from the cylinder cover (A1) and the motion of the piston is transmitted through the cross-head (D) and connecting rod (C) to the crank pin (E), giving rotary motion to the crank shaft (F).

When the piston (B) has moved through part of its stroke to the right, the eccentric (G1) on the main shaft (F) through the eccentric rod (G3) and valve rod (H6) has moved the *slide valve* (H) to the left (and the *piston valve* (H) (Fig. 8a) to the right). The steam passageway (1H2) from the valve chest (A3) to the cylinder (A) is closed. The piston (B) continues to move to the right, due to the expansive force of the steam.

While live steam is being admitted to the cylinder and, in expanding, is acting on the left-hand side of the piston during part of its stroke, the opposite face of the piston is forcing the contents of the cylinder out through passage (2H2) communicating with the exhaust pipe (H4).

At the end of the piston stroke to the right the *slide valve* (H) (Fig. 7) has been moved toward the left (and the *piston valve* (H) (Fig. 8a) to the right), closing the communicating passageway (2H2) to the exhaust (H4). As the valve (H) continues its movement, the passageway (2H2) is opened to the admission of steam from the steam chest (A3) to the right-hand end of the

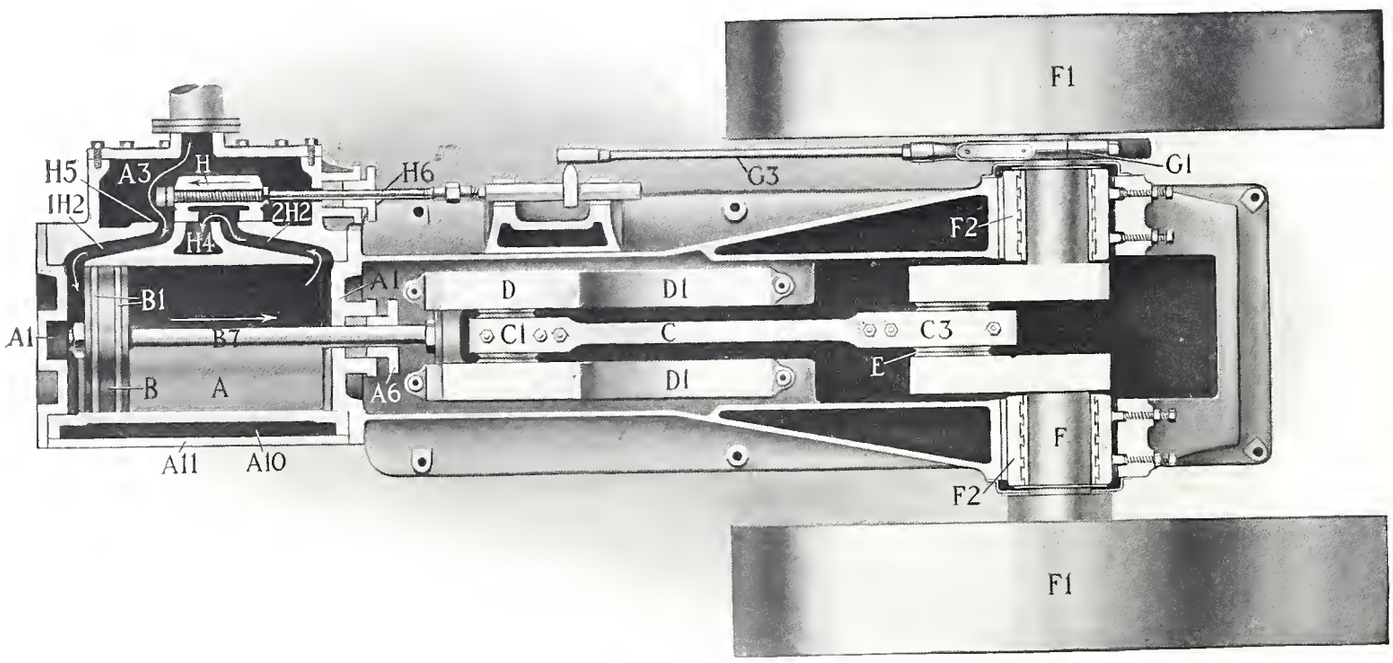

Fig. 7—Part Sectional Top View of Slide Valve Steam Engine

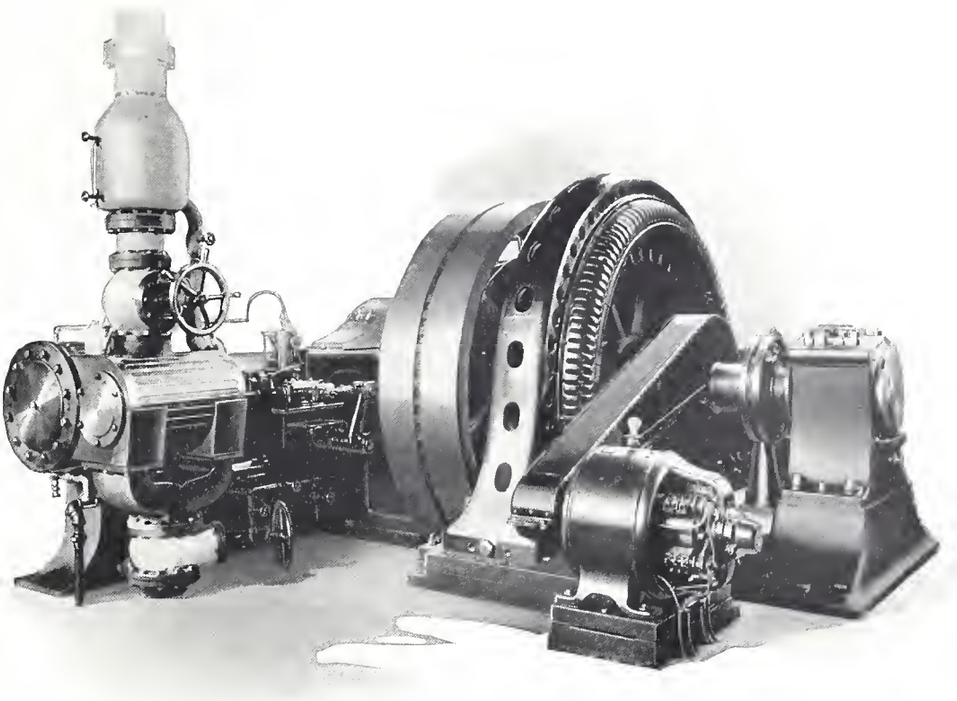

Fig. 8—Photograph of Piston Valve Steam Engine

cylinder (A). The steam expansion forces the piston to the left—and the operation as just described is repeated.

Thus the piston receives a power impulse each stroke, *i.e.*, there are two power impulses for every revolution of the crank shaft (F).

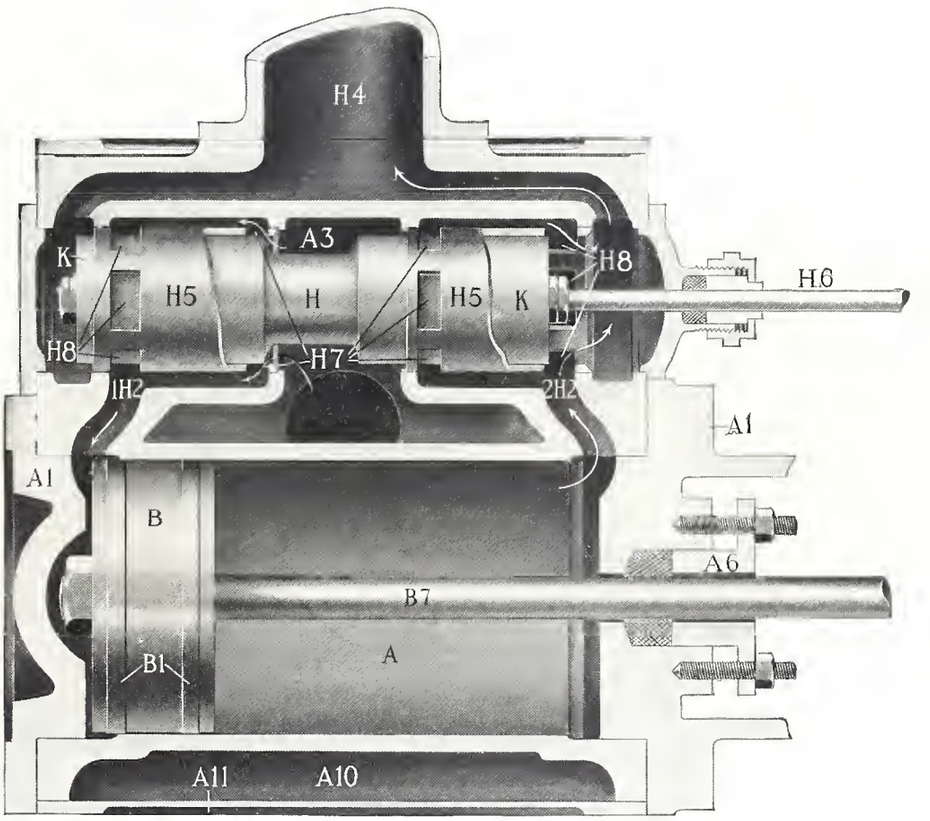

Fig. 8a—Part Sectional View of Cylinder and Valve of Piston Valve Steam Engine

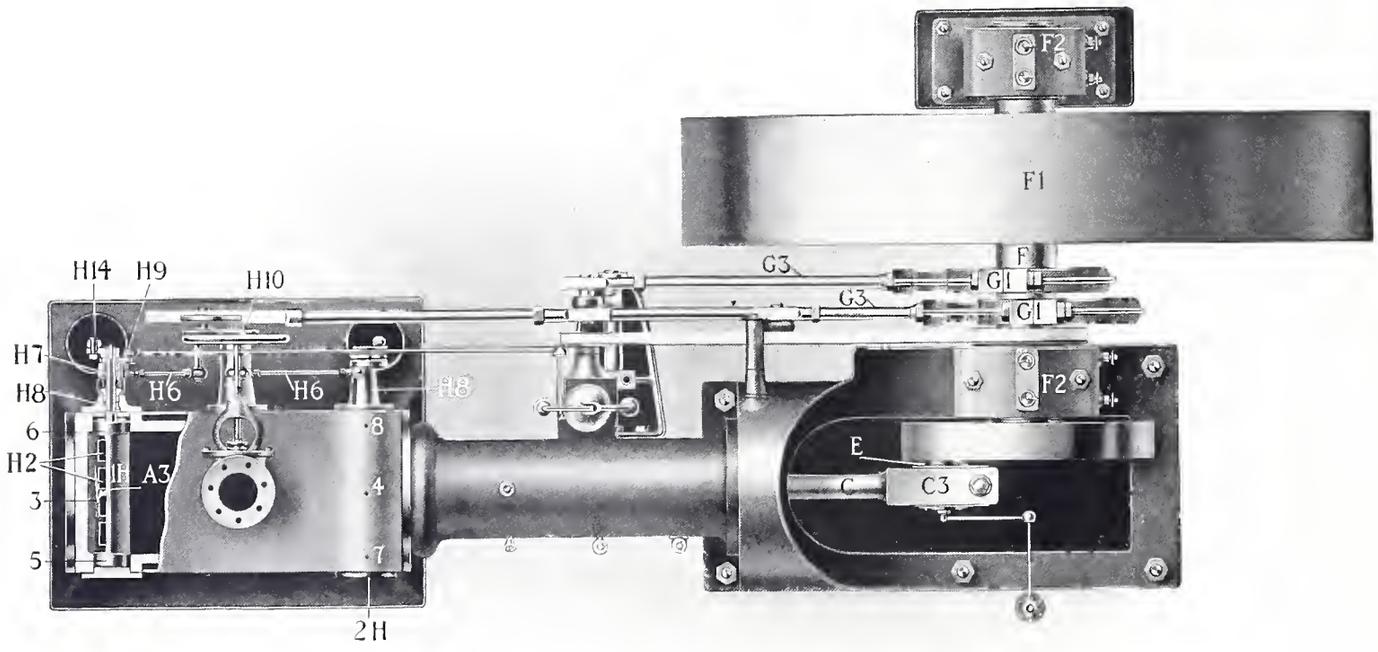

Fig. 9—Top View of the Corliss Valve Engine. Steam Chest Cut Away Showing Steam Valve

Corliss and Poppet Valve Engines

Corliss and poppet valve engines employing two admission and two exhaust valves are called four-valve engines. The principle of operation of these two types of engines is the same.

Poppet valve gear (valve levers, rods and cams) is actuated by the revolving cam shaft (G). (See Fig. 6, page 10.) Generally the Corliss admission valves are operated with one eccentric and the exhaust valves with another eccentric.

Fig. 9 illustrates the position on the engine crank shaft (F) of the steam and exhaust eccentrics (G1), the eccentric rods (G3), the wrist plate (H10) and the valve rods (H6). The steam chest (A3) is partially cut away and the left-hand steam valve (1H) is shown in an opened

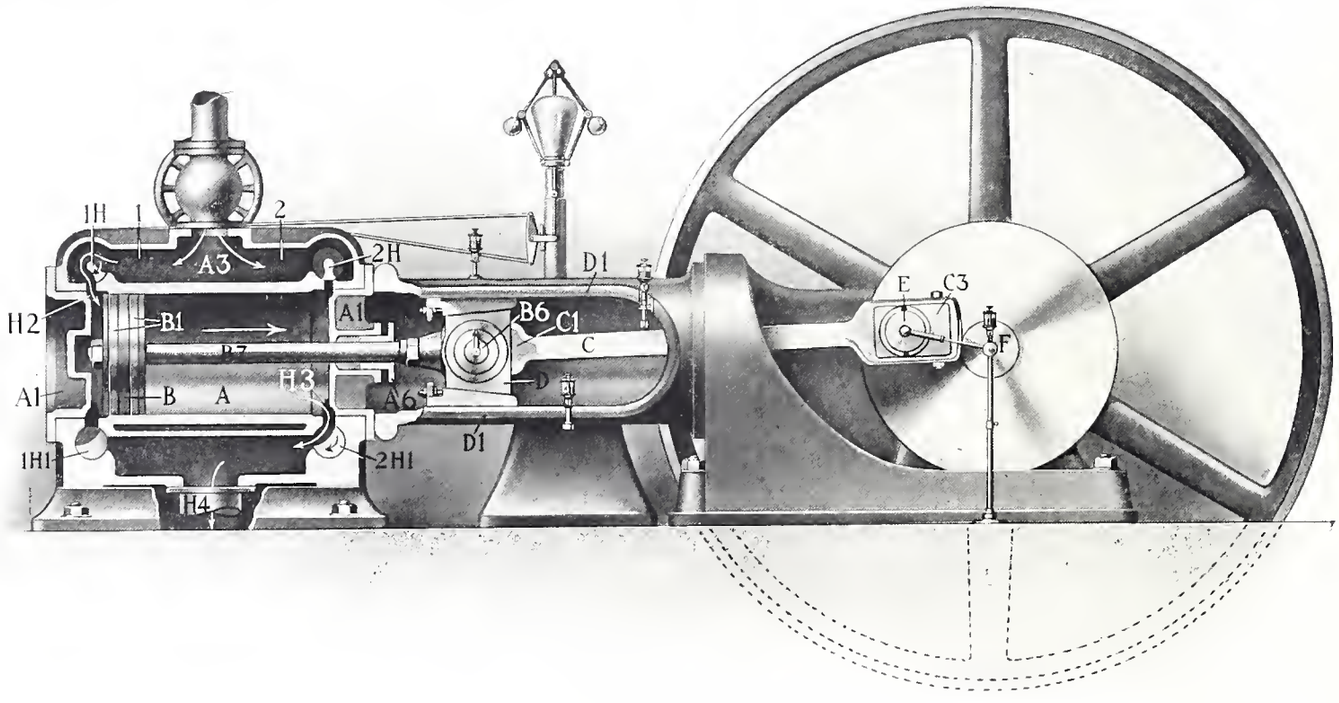

Fig. 10—Side View of the Corliss Valve Engine. Cylinder and Valves Shown in Section

position exposing the steam ports (H2) for the admission of steam from the steam chest (A3) to the cylinder (A).

When the piston (B) (Fig. 10) is in the position shown at the left, the steam admission valve (1H) at the left is open, and steam from the steam chest (A3) passes the valve (1H) into the cylinder (A) between the piston (B) and the cylinder cover (A1). The steam expansion forces the piston (B) to the right. Before the end of the stroke, the admission valve (1H) closes. The expanding steam continues to force the piston (B) to the extreme right.

The contents of the cylinder to the right of the moving piston (B) are forced out through the exhaust valve (2H1) which remains open during almost the entire stroke.

At the end of the piston stroke to the right, exhaust valve (2H1) closes. Live steam is introduced to the cylinder (A) from the steam chest (A3) through the opened admission valve (2H), and the piston is forced to the left.

The contents of the cylinder to the left of the piston are forced out through the opened exhaust valve (1H1) by the moving piston (B).

The piston receives a power impulse each stroke, *i.e.*, there are two power impulses for every revolution of the crank shaft (F).

Uniflow Engine (Fig. 11)

In the uniflow type of steam engine the steam valves, opened alternately, admit steam to the ends of the cylinder; the steam expansion pushes the piston to the opposite end of the cylinder; the waste steam passes out of the exhaust ports or openings (H1) in the cylinder wall at the middle of the cylinder, into the exhaust steam belt (H4).

Steam valves are usually of the poppet type, although the Corliss type valve is sometimes used. There are no exhaust valves.

The cylinder heads (A1), being steam-jacketed, are always as hot as the live steam used. With the reduction in the heat of the steam, due to expansion, the temperature of the cylinder walls gradually decreases toward the center of the cylinder where the exhaust ports are located.

The construction of the uniflow engine minimizes the losses due to radiation and condensation in the use of steam. Consequently it is a power unit of high steam efficiency.

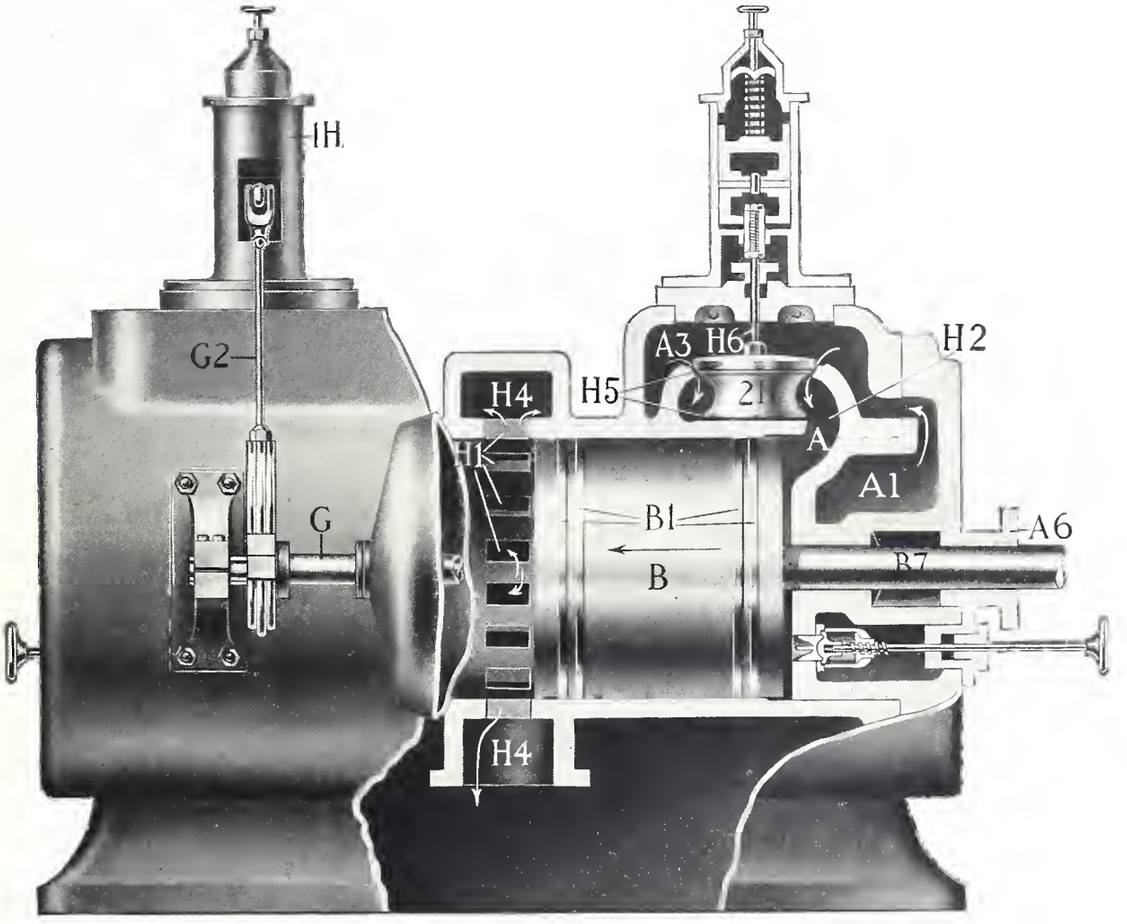

Fig. 11—Side View of the Cylinder of the Uniflow Engine—Cylinder Cut Away Showing Piston, the Exhaust Ports and the Steam Valve at the Crank End

LUBRICATION

Experience has proved that only by the use of the correct grade of high-quality cylinder oil, specially selected to suit the operating conditions of the engine and applied in the correct manner, to the right place, in the proper quantity, will the valves and pistons of steam engines operate at highest efficiency with minimum wear.

Lubrication of steam valves and cylinders is obtained by feeding a minimum quantity of the correct grade of oil with such regularity as will insure an unbroken oil film between the frictional surfaces.

The introduction of the cylinder oil by means of lubricators, the several points of application of the oil and the atomization of the oil feed will be explained in detail, as efficient results are directly dependent upon a knowledge or a complete understanding of these important factors.

Lubricators

There are two main types of cylinder-oil lubricators—the hydrostatic lubricator and the mechanically operated lubricator.

Hydrostatic Lubricator (Fig. 12)

In the early days of steam engineering, one of the most widely used lubricating appliances was the hydrostatic lubricator which operates on the following principle:

Through pipe (3) steam enters the condenser (4) at the top of the lubricator. In this condenser the steam is cooled and condensed into water.

When the valve (5) is open, as is the case when the lubricator is in commission, the water passes through pipe (6) into the bottom of the oil reservoir (7) and, displacing the oil, causes it to leave the reservoir through the open end of the pipe (8) and through the adjusting valve (9) which regulates the feed. The oil rises through the water in the sight-feed glass (10) and enters the steam pipe (1) through the delivery pipe (11).

The gauge glass (13) shows the level of the oil inside the reservoir (7).

The drain cock (14) is for drawing off the water before refilling the lubricator with oil through filling plug (15).

The lubricator is usually attached to the steam pipe (1) supplying steam to the engine or pump.

The length of the pipe (3) should be at least 18 inches in order to produce sufficient steam condensation to assure a flow of oil through the lubricator by water displacement. Sometimes when a large oil feed is demanded the pipe (3) is made in the form of a coil to provide increased cooling surface for steam condensation.

This lubricator is not automatic in action, because it must be started and stopped by hand.

It is difficult to maintain a uniform cylinder-oil feed with a hydrostatic lubricator, especially where a very small feed is required, for the following reasons:

The feed is affected by the change in viscosity of the oil at different temperatures, therefore the feed will vary each time the lubricator is filled and also with the changes in engine-room temperature; small oil passages are liable to be

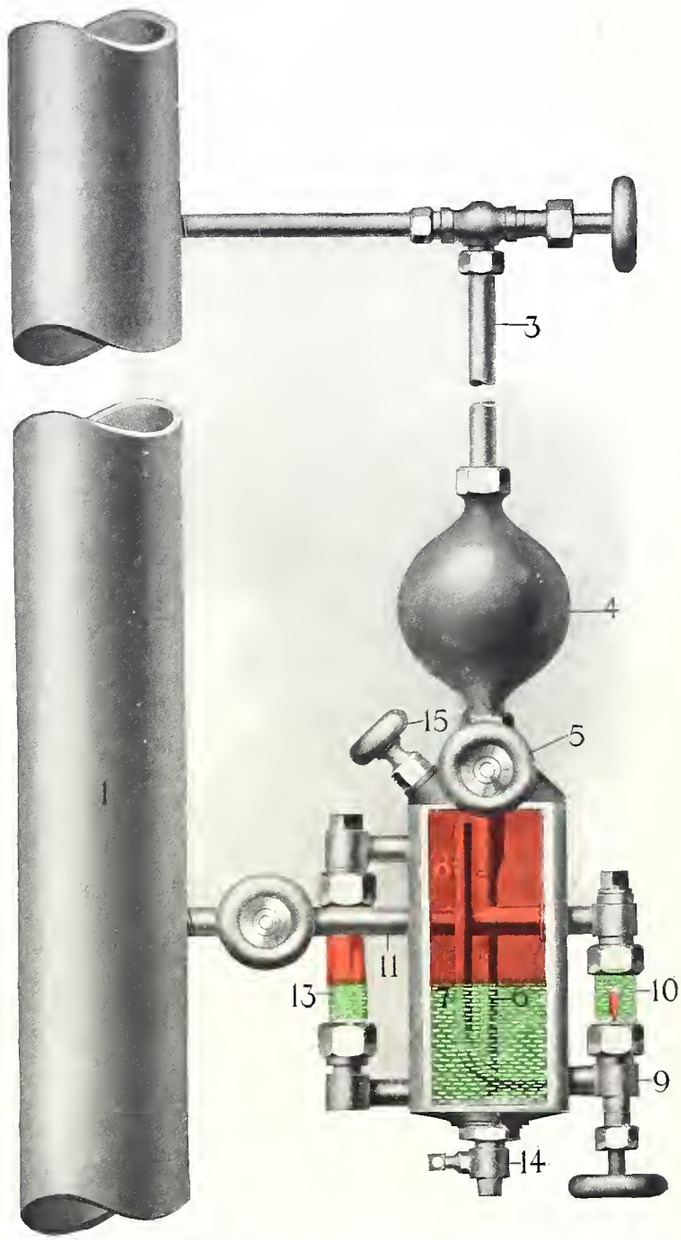

Fig. 12—Part Sectional View of Hydrostatic Lubricator

partially choked with dirt, thus reducing or stopping the oil feed.

A uniform feed of oil is of the greatest importance, otherwise the steam is charged with either too much or too little oil, affecting the economy and efficiency of lubrication.

If the cylinder oil is supplied by a lubricator unreliable in its operation, or if the oil feeds do not introduce the oil in the most positive manner, more oil is required to guarantee the supply, and lubrication will be less efficient than when the oil is properly fed and applied.

Mechanically Operated Lubricators (Fig. 13)

Modern conditions of high steam pressure and high steam temperature make it desirable, and in many cases *necessary*, to use mechanically operated lubricators, which can be relied upon to automatically feed high-grade cylinder oil uniformly and regularly, and in sufficiently small quantities.

Mechanically operated lubricators are located generally upon the engine cylinder or steam chest in a fixed position. They are operated from some moving part of the engine, and therefore start feeding as soon as the engine is started and stop feeding when the engine is stopped.

This type of lubricator is constructed with single and multi-feed delivery pipes. The number of feeds is usually limited to the number of points of application demanded in each case.

Mechanically operated lubricators preferably have sight-feed arrangements for each of the oil feeds, so that the exact quantity of oil passing through each delivery pipe can be observed.

Fig. (13) illustrates an excellent type of mechanically operated lubricator with bull's-eye sight-feed arrangement, on the discharge side of the oil pump.

The oil reservoir (1) contains oil, its level being indicated by the gauge (not shown). The oil plunger (2) draws oil into the pump on the suction stroke and on the delivery stroke discharges the oil through the nozzle (3). The oil drops form around the guide wire (4) and rise through water in the sight-feed. It passes a non-return valve (5) and is forced through the check valve (7), at the extreme end of the oil pipe (6), into the atomizer (8) located in the steam pipe (10). The steam flow atomizes the oil by forcing it through the slots (9) in the spoon-shaped end of the atomizer.

By adjusting nuts (11) and (12) the oil supply can be varied from the smallest amount, say one drop in ten minutes to practically the full capacity of the pump stroke at moderate speeds.

The oil feed is absolutely uniform because it is independent of the oil level in the container, or the pressure against which the pump acts,

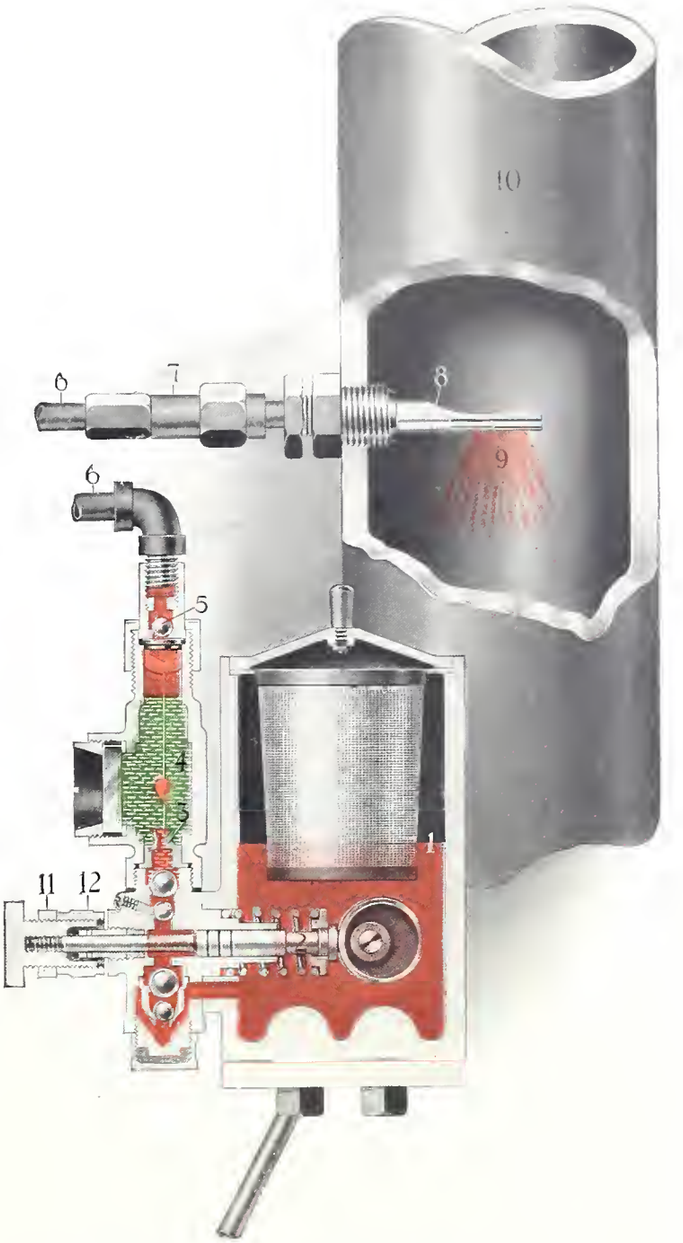

Fig. 13—Part Sectional View of Mechanically Operated Lubricator and Oil Atomizer

and is practically independent of whether the oil is thick or thin.

Mechanically operated lubricators should be so constructed that each feed is independent and subject to separate adjustment and control. It is especially important that all the working parts, valves, etc., should be easily accessible for inspection and cleaning.

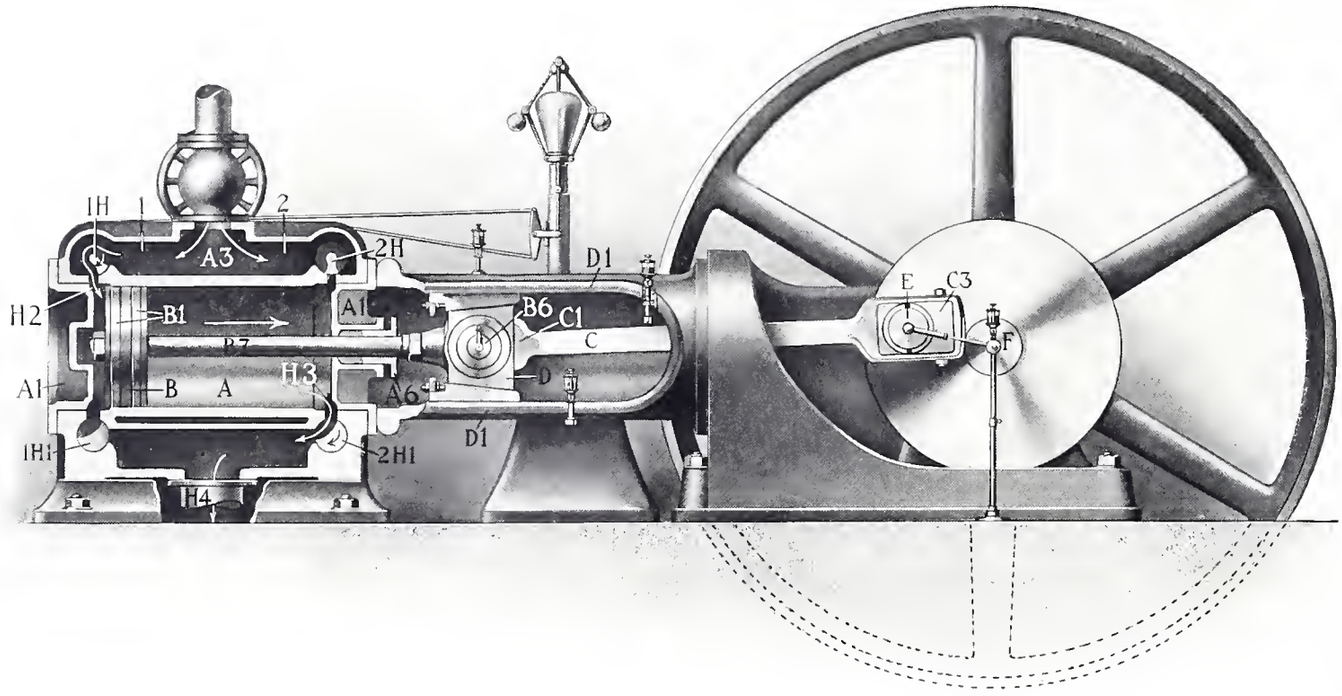

Fig. 14—Side View of the Corliss Valve Engine. Cylinder and Valves Shown in Section

In order to insure that the oil pipe leading from the mechanically operated lubricator is always completely filled with oil, a spring-actuated check valve should be fitted at its extreme end. A spring-actuated check valve is a non-return valve kept closed by a spring.

Lubrication is assured immediately the engine, and therefore the lubricator, starts to operate as the pump pressure opens the check valve, forcing the oil through.

Some mechanically operated lubricators are irregular in action, due to the following causes: Change in oil viscosity with the temperature changes prevailing; variable oil feed with a change in oil level in the container; necessary adjustments of oil feeds by hand, because the lubricators do not operate on the true automatic principle; oil leakage past the pump plungers, and the presence of air trapped in the lubricator.

Points of Application

Steam valves and cylinders are lubricated by introducing cylinder oil into one or several of the following points:

To the steam chest
Over the valves
Direct to the cylinders
To the piston rod
Into the steam line

To the Steam Chest

This was one of the earliest methods of application of cylinder oil.

The oil is introduced into the steam chest (A_3—of the slide valve engine Fig. 7, page 12), in the path of the steam, at such a point (not shown) that it is partially broken up into smaller drops and swept by the steam through the steam ports uncovered by the slide valve (H).

In Corliss valve engines the oil is introduced as shown at two points (1 and 2) (Fig. 14). The flow of steam to the left carries the oil along with it to the left-hand valve (1H), and the flow of steam to the right carries the oil along with it to the right-hand valve (2H). The oil, after passing the valves, enters the cylinder (A) and provides lubrication for the piston (B). Finally, the oil reaches and lubricates the exhaust valves ($1H_1$) and ($2H_1$).

The piston valve engine should never be lubricated by the application of oil direct to the steam chest, nor should the poppet valve engine be lubricated by this method.

Over the Valves

On Corliss valve engines, oil is sometimes delivered at points (3 and 4) (Fig. 15) over the centers of the Corliss valves (1H) and (2H) or

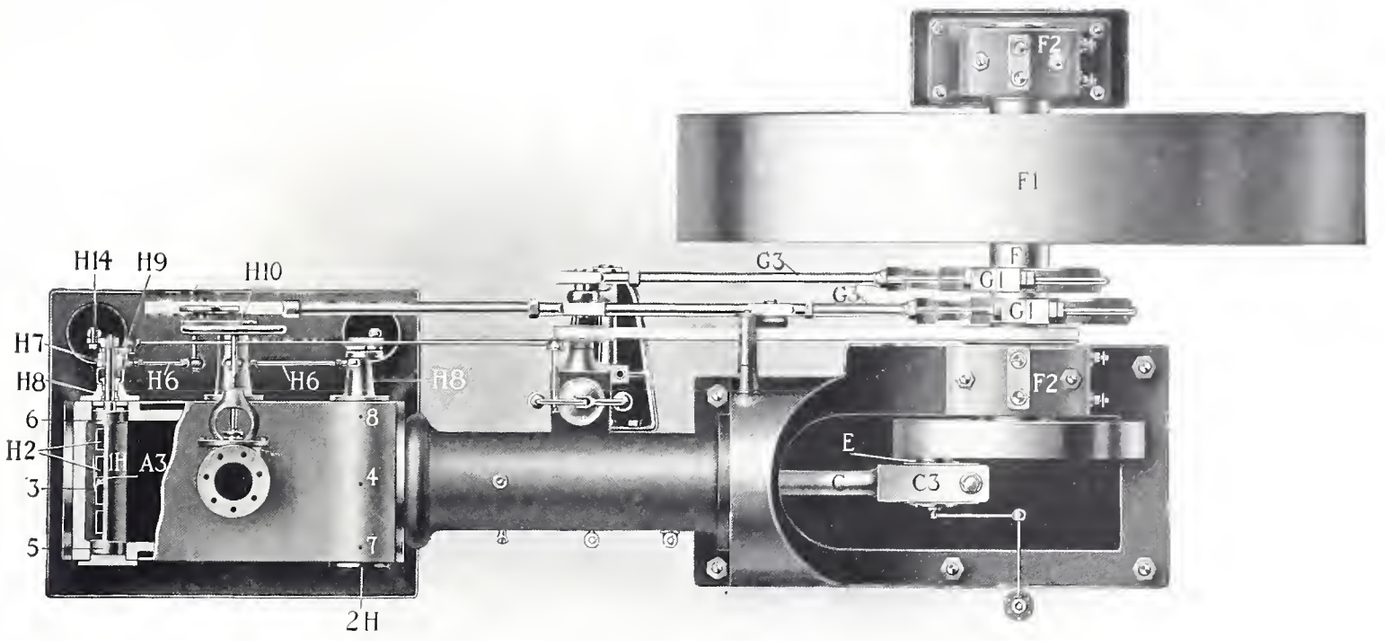

Fig. 15—Top View of the Corliss Valve Engine. Steam Chest Cut Away Showing Steam Valve

at two points (5 and 6) and (7 and 8) (Fig. 15), one at each end of each Corliss valve.

As it is the ends of the valves that require most lubrication, feeding to the ends direct is preferable to feeding at the center (3 and 4). In both cases, however, the flow of steam sweeps the oil into the cylinder (A) (Fig. 14), and out through the exhaust valves (1H1) and (2H1), supplying lubrication to these parts.

Piston valves are sometimes lubricated by two oil feeds, one over each end of the valve (not shown).

Slide and poppet valves should never be lubricated by the application of oil direct to the valves, although present construction would permit of this method if desired.

Direct to the Cylinders

Sometimes, in the case of large steam engines, oil is introduced into the cylinder, either at the top or at the bottom. The oil thus introduced is gradually spread by the piston (B) over the cylinder walls (A) and forms a lubricating film.

To the Piston Rod

Oil may be applied to the piston rod (B7) (Fig. 14) externally, *i. e.,* outside of the piston rod gland (A6), either by oil dropped on the piston rod (B7) from a lubricator (not shown), or by means of an oil swab (not shown) resting on the rod. The greater portion of the oil applied externally is scraped off by the gland (A6) and runs to waste.

This method of application is employed chiefly in vertical marine engines, where it lubricates both the piston rod and the cylinder.

Oil may be introduced, particularly under conditions of high temperature and pressure, directly into the piston rod gland (A6), insuring its better distribution inside of the cylinder.

The piston rod, particularly under high-pressure conditions, frequently shows evidence of uneven oil distribution, it is scratched all over and has the peculiar raw, polished surface indicative of wear. For this reason a relatively large quantity of oil is required to insure a complete lubricating oil film.

Lubrication of valves and cylinders by these direct methods has this disadvantage: as the cylinder oil is of very heavy viscosity, it breaks up and spreads with difficulty; it fails to reach some parts, and is likely to overlubricate other parts.

Into the Steam Line

This is the best method of application and embodies an entirely different principle. Instead

of the application of oil to the various parts direct, the oil is broken up into many minute drops, in which form it is readily carried and spread by the steam.

The oil is introduced into the steam line preferably on the boiler side of the engine stop valve, thus lubricating the spindle of the valve, and making easy its manipulation when cutting in or cutting out the steam supply.

The steam entering the engine comes in direct contact with all the internal parts requiring lubrication, thus insuring distribution of cylinder oil.

The cylinder oil should be introduced into the steam line not more than twelve feet back of the stop valve.

Superheated steam, which is very dry and hot, is not a good carrying medium for the cylinder oil; therefore the oil should be introduced just back of the engine stop valve when superheated steam is employed.

Steam is sometimes used for jacketing the cylinders and heads of the engine before entering the cylinder. Under these conditions the cylinder oil will be partially precipitated on the walls of the passages if it has been introduced into the steam line before the engine stop valve. To overcome this difficulty, oil is introduced directly into the valve chambers where the flow of steam, passing through the valves, will break up and distribute the oil.

Oil Atomization

The best method for insuring perfect distribution of the cylinder oil is the atomizing method. By this means the oil is introduced through an atomizer (8—Fig. 13) into the center of the flow of steam. The steam impinges with great velocity against the spoon-shaped end of the atomizer (8) and forces the oil through the slots (9). The oil is thoroughly broken up into an exceedingly fine spray and enters the engine with the steam.

The atomized oil lubricates the spindle of the engine stop valve.

It lubricates the steam valves as the steam, in passing, throws down a slight portion of the oil on these parts.

It is thoroughly distributed in the form of a uniform coating or film over the cylinder walls. The piston rod receives proper lubrication in a more economical manner than by the direct external application of the lubricant to the piston rod.

The exhaust valves also receive their share of lubrication. And the exhaust steam, if it be carried over to the low-pressure cylinder of a compound engine, or to the intermediate-pressure and low-pressure cylinders of a triple-expansion engine, will distribute finely atomized oil and thus assist in the lubrication of these cylinders.

If between cylinders of a compound or triple-expansion engine there are large receivers, which may perhaps be utilized for re-heating the steam, these receivers will act as oil separators. In such cases, it frequently becomes necessary to feed oil direct to the intermediate- and low-pressure cylinders; but this should preferably be done by introducing the oil into the steam inlet pipe leading to these cylinders from the receiver, rather than by feeding the oil direct over the valves or into the cylinders.

Atomizing the oil and using the steam as the oil-spreading medium results in the most efficient oil distribution, so that not only is friction reduced, but only a small quantity of oil is required for correct lubrication.

As this method relies upon the velocity of the steam to break up or atomize the oil, it will fail only in very exceptional cases where the velocity of the steam is too low, and then only where the engines for some reason are operated at considerably less than full load.

When the atomization method supersedes the direct method, supplying oil to the outside of the piston rod can usually be immediately dispensed with, and, due to the better internal distribution of the cylinder oil, the surface of the piston rod will soon assume a glossy, oily appearance, indicating that wear has ceased and that the piston rod surface is acquiring a hard, dull-polished skin.

Having considered the different types of steam engines with reference to their construction and cylinder arrangement, the factors influencing their performance, the detailed operation of engines employing the different types of steam valves, the types of lubricators employed and the points of application of the oil, the influence of lubrication may now be considered in detail.

Lubrication Requirements of Internal Parts

The internal moving parts of the steam engine, comprising valves, valve rods, piston and piston rods, are exposed to steam temperature conditions. With the exception of the piston rods, and the valve rods of slide and piston valve engines, none of the internal parts are exposed to view, so that the conditions of lubrication cannot easily be inspected.

The correct lubrication of steam valves and cylinders is therefore of much greater importance and much more difficult to accomplish than the lubrication of the external moving parts, consisting of the cross-head pin and guides, crank pin, main bearings, eccentrics, etc.

Slide Valve (Figs. 3, 7)

As the slide valve is positively operated, it can theoretically run at any speed; but in actual service, due to its unbalanced construction, it is not operated at as high a speed as the piston valve.

The flat surface of the slide valve which rubs against the valve seat is difficult to lubricate, particularly where the slide valve is large. In some extreme cases, oil grooves are cut in the valve or in the valve seat to assist in spreading the oil all over the frictional surfaces.

The use of slide valves is restricted to a maximum steam pressure of, say, 120 lbs. or a maximum steam temperature of, say, 450° F. This is due to the large flat frictional surfaces of the slide valve and its seat, and the difficulty of introducing the oil thoroughly between them, owing to the great pressure on the valve.

Excessive steam pressure will prevent the formation and maintenance of the oil film, resulting in metallic contact of the rubbing surfaces with excessive friction and wear.

Excessive steam temperature will result in unequal expansion and distortion of the valve and valve seat. Steam will leak past the valve seat, causing cutting of the surfaces. As the oil film is thinned out, due to the high temperature, it will be unable to resist the pressure between the frictional surfaces, and metallic contact and wear will follow.

Upon removing the cover from the steam chest for inspection, excess friction of the slide valve is always indicated by a dryness of the rubbing surfaces, which will show wear and bright streaks of cutting.

It is important that the cast iron of the valve seat should be slightly harder than that of the valve. Thereby the possibility of wear on the valve seat is reduced to the minimum.

Improper lubrication results in abrasion and cutting; excessive leakage of steam takes place and wipes away the lubricating oil from the valve seat, necessitating an increased consumption of oil. Friction of the slide valve frequently produces groaning during operation, and the excessive resistance in moving the valve causes the eccentric rod to vibrate.

With efficient lubrication the valve operates without noise; the eccentric rod works smoothly and when inspected the friction surfaces of the valve and valve seat have a polished, dull, glossy appearance.

Experience has proved that when the oil is introduced into the steam line and atomized, the oil is most thoroughly distributed. In many cases, atomizing the oil has furnished lubrication which has overcome groaning and other troubles with slide valves where direct methods of application had given insufficient results.

It is obvious since slide valves operate under trying conditions that for the best results the highest grade of cylinder oil especially selected to suit the conditions should be used.

Corliss Valve (Figs. 4, 9, 10)

The Corliss valve has a rotating motion through a small arc over a *cylindrical* surface, whereas the slide valve has a short stroke reciprocating motion, *sliding* back and forth over a *flat* surface.

Conditions of high steam pressure and temperature, therefore, affect the lubrication of the Corliss valve in the same manner that they affect the slide valve, with this difference—the admission Corliss valves are not mechanically operated during their closing period, but are closed by vacuum or spring-controlled dash pots. Poor lubrication may sometimes be indicated by the sluggish closing of the valves. Otherwise, excessive friction is indicated by groaning and vibration of the valve and its operating mechanism, as in the case of slide valves. Upon the removal of parts for inspection, indications of good or bad lubrication are the same as experienced with slide valves.

The introduction of the oil over the valves is wasteful or inefficient, or both; whereas, by the introduction of oil into the steam line, it is quickly atomized and swept by the steam to the wearing surfaces at the ends of the valves, resulting in the free, easy motion of the valve, no noise, no wear and no leakage of steam.

Piston Valve (Fig. 5)

There is only a slight pressure between the piston valve and the cylindrical sleeve in which it moves with a reciprocating motion of short stroke. This type of valve is used at very high speeds, and the surface to be lubricated is correspondingly great.

Exposed to great pressure or high temperature, the piston valve, being symmetrical, expands uniformly, and the pressure between the valve and the sleeve is the same at all points. Steam pressure and temperature, therefore, have little effect on the operation of the piston valve.

The signs of good or bad lubrication are similar to those indicated by the slide valve. Owing to the pressure on the valve being equalized and to its cylindrical construction, the piston valve is easier to lubricate. It is important, however, that the oil be well distributed, and here, again, experience has shown that this can best be accomplished by the atomization method of lubrication.

Poppet Valve (Fig. 6)

The poppet valve is lifted from its seat and quickly drops back. There is no sliding motion of the valve on its seat. Consequently no lubrication of the valve seat is required.

The long valve spindle has a very short motion in its guide. Its surface is broken by a number of shallow grooves an inch or so apart, which fill with water of condensation from steam leakage in the valve guide.

Internal lubrication by atomized oil in the steam supply will furnish most satisfactory lubrication. External lubrication used too freely will cause sticking of the valve, owing to the fact that the clearance is small between the valve spindle and its guide.

The oil for cylinder lubrication should be used sparingly. To insure uniform distribution the oil should be introduced by the atomization method.

Piston and Cylinder

In vertical steam engines the pressure between the piston, piston rings and the walls of the cylinder is moderate. For this reason, less oil is required than for horizontal steam engines.

In horizontal steam engines, in addition to the pressure between the piston rings and the cylinder walls, there is the pressure due to the weight of the piston sliding over the bottom of the cylinder.

In large horizontal steam engines, the extra friction, due to the weight of the piston, is frequently minimized by the addition of a tail rod, an extension of the piston rod out through the back cover, connected to a tail-rod support. In this way, by making the piston rod sufficiently rigid, the whole or part of the weight of the piston is supported externally by the cross-head and tail-rod supports. The duty of the piston rings, then, is simply to prevent leakage of steam from one side of the piston to the other.

It must be remembered that the temperature of the oil film on the cylinder wall is high and that excessive pressure may easily destroy the film; friction and wear will result.

The piston rings are made of softer metal than the cylinder and can be replaced at less cost if subjected to undue friction and wear.

It is always an advantage to have the edges of the piston rings rounded off. When they are sharp, they have a tendency to scrape off the oil on the cylinder walls; when they are rounded, they do not destroy the oil film, and lubrication is provided with economy.

On opening up the steam cylinders for inspection, the cylinder walls should present a rather dull appearance, due to a thin coating of oil. The presence of oil can be ascertained by striking a piece of paper on different parts of the cylinder walls.

When the oil film is wiped off, the surface underneath should appear dull and glossy. If any wear has taken place, the surface will be bright, as if raw-polished with fine emery cloth, and although actual scoring may not have taken place, there will be found fine streaks, indicating wear.

Wear not attributable to mechanical faults or to a change in operating conditions may be due to a variety of causes, such as the use of an

improperly selected oil or one too low in quality; an unreliable lubricator; an unsatisfactory method of applying the oil, or too economical an oil feed.

Gland Packing

The function of packing glands used for piston and valve rods is to prevent steam leakage *outward* in high-pressure cylinders, and air leakage *inward* in low-pressure cylinders of condensing engines.

Full and efficient lubrication of the packing glands is essential, as a perfect seal can only be obtained by the presence of a complete oil film on the rods.

There are many types of piston and valve-rod glands in service, but they can be divided into two main groups, *viz.*, glands with soft packing and glands with metallic packing.

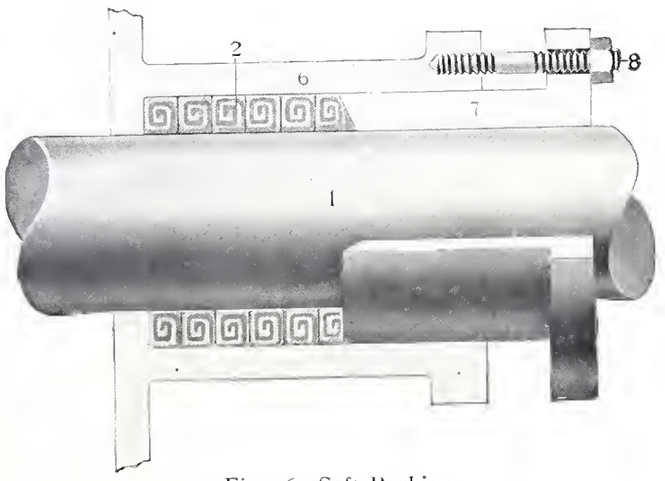

Fig. 16—Soft Packing

Soft Packing (Fig. 16)

Soft packings are only used under moderate steam conditions. The friction between the packing and the piston rod is always comparatively high; and if the packing (2) is screwed up too tight, undue pressure is produced, which causes grooving or scoring of the rod; it then becomes difficult to keep the gland from leaking.

In reversing engines, such as colliery hoisting and haulage engines, rolling-mill engines, etc., the engine is reversed by changing the movement of the steam valves with relation to the position of the pistons.

The reversing movement of the valve is performed by hand in the case of a small engine, and by a special reversing engine in the case of a large engine. It is obvious that the pull required to reverse the engine is influenced by the frictional resistance offered by the valves moving on their bearing surfaces and by the additional resistance of the valve rods moving in their glands. The pull is therefore directly dependent upon efficient lubrication.

Where the valve rods have been lubricated externally by the direct method, which is wasteful and inefficient, a change to the atomization method effects a marked improvement. The valve rods receive lubrication when inside the valve chest and furnish efficient lubrication to the packing. As a result, external lubrication of the valve rods can be dispensed with altogether.

Every improvement in the grade of cylinder oil used or in the method of its application will be immediately noticeable in the smoothness of operation and, in the case of reversing engines, in the pull required to shift the reversing lever.

Metallic Packing (Fig. 17)

Metallic packing is superior to soft packing for high steam temperature conditions.

It should be self-adjusting as the deflection and movement of the piston rod should take place without creating undue pressure in the packing; the packing rings should only exert a slight pressure against the piston rod, their elasticity automatically maintaining the piston-rod seal.

Metallic packing is durable, reliable and presents a positive problem of lubrication. The gland friction is low and there is less danger of scoring the rods as compared with the use of soft packing, which must be frequently taken up by hand and periodically renewed to prevent leakage.

Metallic packing should always be employed

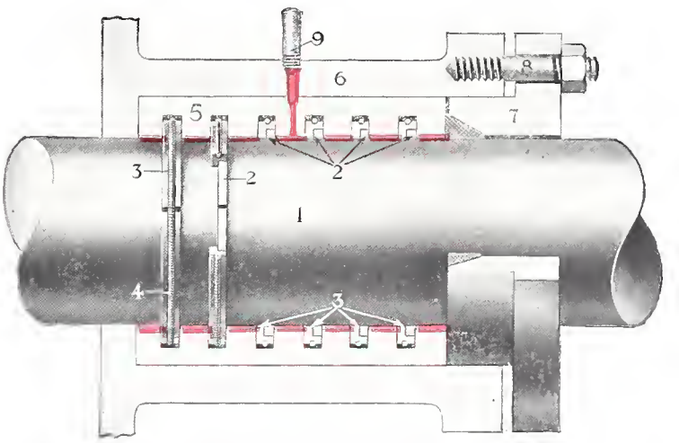

Fig. 17—Metallic Packing

when high-pressure superheated steam is used as soft packing will not withstand the effect of high pressure nor high temperature.

When the atomization method of lubrication is employed with moderately superheated steam, it is frequently unnecessary to lubricate the metallic packing direct. In the case of highly superheated steam, however, it is generally necessary to have a direct feed of cylinder oil into the packing.

Only the highest grade of cylinder oil should be used for this purpose. It should be fed uniformly and sparingly, as excess oil will remain stagnant in the packing casing where, being exposed to high temperature, it is inclined to bake into carbonaceous deposits.

Detailed consideration has been given to the several internal parts of a steam engine requiring lubrication, the methods employed for introducing the oil, and the points of application of the oil. In addition, it is necessary to give due consideration to the influence of operating conditions on the selection of oil.

SELECTION OF OIL

The object of internal lubrication in a steam engine is:

First—To form a *lubricating film* between the rubbing surfaces and thus replace metallic friction with fluid friction.

Second—To form an *oil-sealing film* and thus prevent leakage of steam past the valves, pistons, and gland packings.

It is desirable under certain conditions to extract the oil from the exhaust steam and thus eliminate the objection arising from oil that is carried back into the boiler with the feed water.

If an *oil too heavy in body* be used, it will not atomize readily. Poor distribution and excessive consumption will follow. Due to its heavy body, the fluid frictional losses will be higher than they should be. Such an oil apparently assists in the accumulation of deposits in the cylinder if the steam carries over impurities to the engine, particularly under high pressure and superheat conditions.

If an *oil too light in body* be used, it will be readily atomized and distributed, but it will be unable to withstand the pressure between the rubbing surfaces; metallic contact will take place, resulting in undue wear, and an excessive quantity of steam will leak past the valves and piston rings.

If *too much oil* be used, wastage will occur, and lubrication will not be any more efficient than if the right quantity of oil is used. Under superheated steam conditions, the excess oil is positively detrimental, leading to the formation of carbonaceous deposits.

If *too little oil* be used, a complete oil film will not be maintained between the frictional surfaces. Not only will heavy friction and wear occur, but there will be excessive leakage of steam past the moving surfaces, resulting in apparently dry cylinder walls.

There are a few vertical engines employing dry steam which will not groan when operated without cylinder oil. Sufficient oil passes into the cylinder from oiling the rods to prevent groaning, particularly when the rods extend through the top cylinder cover. Correct lubrication is not attained. Non-lubrication results in excessive friction and leakage of steam past the moving surfaces. The excess cost of operation in such cases will amount to many times the cost of correct lubrication.

If an *oil too low in quality be used*, it will not maintain a complete oil film on the internal surfaces, notwithstanding a liberal feed, and losses due to friction and steam leakage will be high, the valve rods will vibrate and upon examination the rubbing surfaces will appear dry.

Under conditions of high pressure, and particularly under conditions of superheat, the use of such an oil will cause excessive wear, frequently resulting in the formation of carbonaceous deposits, due to decomposition of the oil.

With a *high-quality* oil in use, correctly selected for the conditions, a complete lubricating film will be maintained on all the internal surfaces. Moreover, this film will be maintained with the lowest consumption of oil. Therefore, the cost of lubrication will be low and the losses, due to the fluid friction of the oil, as well as the leakage of steam past the moving surfaces, will be reduced to a minimum.

For conditions of high steam pressure and superheat, the use of the correct high-grade cylinder oil will also mean that, rightly applied and in the right quantity, both the formation of carbonaceous deposits and excessive wear will be minimized.

Influence of Operating Conditions

Engine Load

Steam engines are usually designed to operate at a constant speed. Load variations are taken care of by the volume of steam admitted to the cylinder necessary to maintain this speed. At full engine load the velocity of the full volume of steam passing through the steam pipe to the engine has the ability to break up into small drops and distribute the cylinder oil introduced through the atomizer.

Under light engine load the volume of steam and its velocity flow are much reduced. This is a vital point and should be carefully weighed in making the selection of cylinder oil which must be readily atomized and distributed under the prevailing engine load conditions.

The volume and velocity flow of high-pressure steam at full load will readily atomize and distribute a heavy-bodied cylinder oil.

The volume and velocity flow of low-pressure steam at full load will atomize and distribute a light-bodied oil to greatest advantage.

A reduced volume of steam per stroke under light load conditions at any pressure can only atomize and efficiently distribute a light-bodied cylinder oil.

Engine Speed

Small steam engines operate at high speed, making short, quick strokes, and the volume of steam per stroke under light load conditions is so small that only a light-bodied, quick-acting oil will fulfil lubrication; this is true regardless of the steam pressure employed.

Wet Steam

The lubrication of a steam cylinder is a more complicated problem if wet steam conditions exist than if dry steam be present.

When the steam is wet it has a tendency to wash the oil film from the internal surfaces of the steam engine. In compound or triple-expansion engines, even if the initial steam is dry, the drop in pressure produces condensation, so that when the steam arrives at the low-pressure cylinder it is very wet.

In order to lubricate cylinders under wet steam conditions, the cylinder oil must be possessed of great endurance, and must be of such quality that it will combine readily with the moisture and cling to the cylinder walls.

In large compound steam engines, it is therefore necessary to use one grade of cylinder oil for the high-pressure cylinder and a different grade of cylinder oil for the low-pressure cylinder for most efficient lubrication.

Superheated Steam

Moderately superheated steam will enter the high-pressure cylinder in a dry condition, but during the steam expansion in the cylinder it will cool, and towards the end of the stroke it will be condensed.

Highly superheated steam in use will not be subjected to condensation in the cylinder of the engine operating at full load. A small quantity of the correct heavy-bodied cylinder oil will furnish most efficient lubrication. The existence of friction and high heat has a tendency to decompose unsuitable oil and form carbonaceous deposits, therefore only a high-quality cylinder oil should be selected.

The use of highly superheated steam on an engine operating under average light load conditions means a relatively small steam volume per stroke, which, though introduced in the cylinder in a dry condition, at the end of the stroke will be subject to condensation.

Under these conditions a medium-bodied high-quality cylinder oil will furnish most efficient lubrication.

Cylinder Oil in Exhaust Steam

Low-grade mineral and compounded cylinder oils are difficult to separate from the exhaust steam.

The best grades of mineral cylinder oils separate more easily from the exhaust steam and feed water than do compounded oils; it will, however, be found that to satisfy lubrication more oil is required when using a mineral cylinder oil than when using a compounded cylinder oil.

The best results will frequently be produced by using the oil which will give best and most economical lubrication in the steam engine, so that there will be only a small quantity of oil present in the exhaust steam.

PART II

Boiler Plant and Steam Production; Steam; Exhaust Steam; Oil in Exhaust Steam; Extraction of Oil; Feed Water Treatment.

BOILER PLANT AND STEAM PRODUCTION

Steam, since it is the operating medium of steam engines, influences to the highest degree the lubrication of valves and cylinders. In order fully to appreciate this influence, we will now describe a typical boiler plant for the generation of steam and discuss steam quality and its value as exhaust steam.

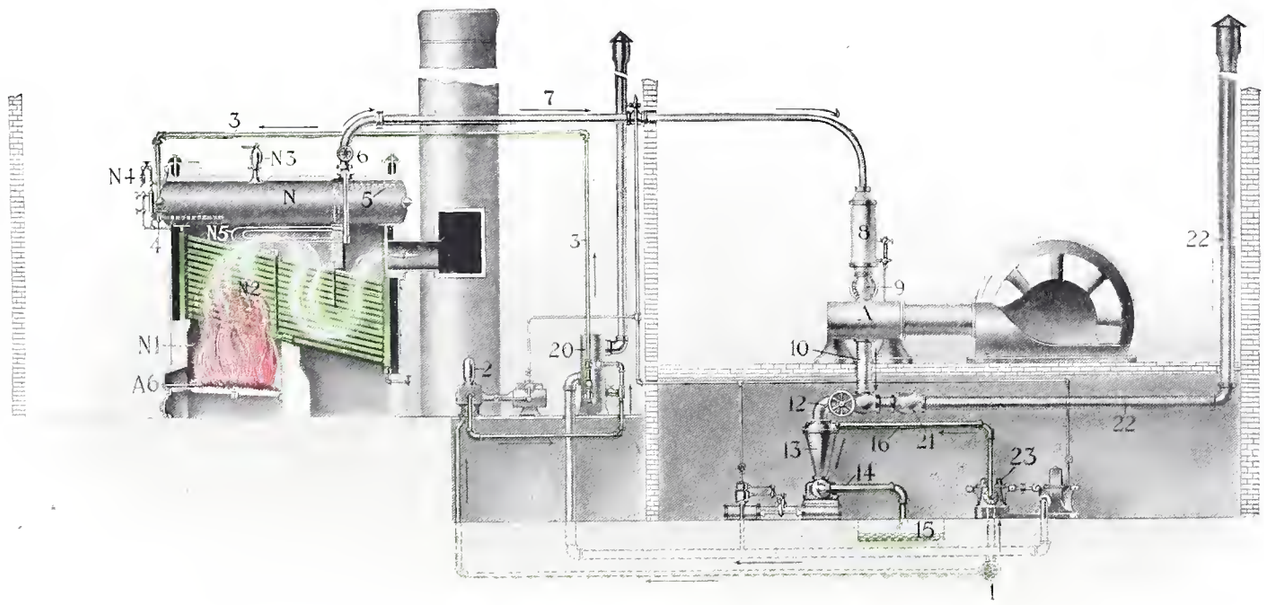

Fig. 18—Boiler Plant and Jet Condensing System

Boiler Plant (Fig. 18)

The boiler (N) which is usually set in position and covered with brick or other insulating material is filled with water to a certain level. The flames and the hot gases from the furnace (N_1) pass into or through the boiler tubes (N_2) and heat the water in the boiler until it boils, *i.e.*, steam is developed.

The steam leaves the boiler (N) through the dry pipe (5) and boiler stop valve (6), and passes to the steam engine (A), through the steam pipe (7), usually covered with insulating material, steam separator (8) and engine stop valve (9).

A safety valve (N_3) on the boiler controls the maximum degree of steam pressure that can be developed inside the boiler. If more steam is developed than is used by the steam engine, the surplus steam will accumulate in the boiler under greater and greater pressure, until finally the safety valve "blows," that is, lifts from its seat against the pressure of a heavy weight or a powerful spring. The excess steam blows off into the air.

Before starting the steam engine, the boiler stop valve (6) and the engine stop valve (9) are kept closed until the proper steam pressure is developed in the boiler.

If a high steam pressure is carried, the water must be heated to a higher temperature before it will develop steam. A certain steam temperature always corresponds to a certain steam pressure, as shown in Table II, page 11.

Water boils away in the form of steam and it becomes necessary to replenish the water in the boiler, the object being to keep as nearly as possible a constant water level.

The boiler is usually replenished by means of

the boiler feed pump (2), which draws water from an outside source of supply (1) or perhaps from the hot well (15), and pumps the water under pressure through the pipe (3) and non-return valve (4) into the boiler (N).

If the steam engine has to develop more power in order to cope with a higher load, more steam is required and more fuel must be burned.

With insufficient fuel the steam pressure will drop until finally it becomes too weak to operate the engine. A steam-pressure gauge (N4) is therefore attached to the boiler and should be watched, and the firing of the boiler should be so performed as to maintain a constant steam pressure.

With hand-firing, nearly always used in small boilers, frequent firing with a small quantity of coal produces a clean, bright and economical fire. Irregular firing with larger quantities of coal produces dense smoke due to incomplete combustion. The soot also tends to deposit upon the boiler tubes (N2), reducing the heat efficiency of the boiler.

In large boiler plants, mechanical stokers automatically throw into the furnaces the right quantity of coal, keeping a bright and economical fire. They also automatically remove the ashes and clinkers from the furnaces.

Where the chimney is low, or where, for some other reason, the natural draft is insufficient, it is necessary to provide an artificial draft by fans.

STEAM

Steam, apart from the fact that it may be of high or low pressure, may be dry or wet saturated steam or superheated steam.

The term "saturated" is used in this sense to indicate that the steam is saturated with a degree of heat corresponding to the pressure at which it is generated. The term "saturated" does not apply to moisture in the steam.

Dry or Wet Saturated Steam

When dry steam leaves the boiler it is called dry saturated steam.

Under certain conditions the steam will leave the boiler in a wet condition. When, for example, the boiler is forced above its normal capacity, or if the water level in the boiler is too high, the water boils violently, so-called priming takes place and the spray or foam from the water surface goes over into the steam pipe with the steam. The steam in this condition is called wet saturated steam.

It is in order to prevent the bulk of this water from being carried over with the steam that various so-called anti-priming devices are frequently employed, such as the dry pipe (5) illustrated in (Fig. 18).

If the steam pipe (7) is long or not properly covered, the steam, during its passage through the pipe, will be cooled and partially condensed into water. This water of condensation will be carried along with the steam towards the engine, together with any water that may have been carried over from the boiler. Therefore, the steam pipe (7) should be well protected with insulating material to minimize condensation.

Water in the steam is generally and should always be removed by the steam separator (8). But where the steam is very wet, it is difficult, even with a good separator, to prevent some of the water from entering the steam engine.

Superheated Steam

Superheated steam passes from the boiler through a superheater. The superheater (N5, Fig. 18) is a system of pipes or tubes placed in the path of the hot gases from the boiler on their way to the chimney.

The steam from the dry pipe (5) in passing through these heated tubes is heated above its saturated steam temperature, and is, therefore, called superheated steam.

For instance, saturated steam at 160 pounds boiler pressure has a steam temperature of 370° F. In passing through the superheater, the temperature may be increased, say 100° F. The steam leaving the superheater is then called superheated steam, having a temperature of 470° F.

The water which has been carried over from the boiler during periods of priming contains impurities, either solids or salts in solution. When this water evaporates in the superheater the impurities will accumulate in the superheater tubes in the form of a dry dust, which is blown over

with the steam into the engine and interferes with proper lubrication.

The steam separator (8) is expected to remove rusty scale and impurities carried over from the boiler or which have broken loose from the inside of the steam pipes; also fine, oxidized scale carried over in the form of a fine black dust from the inside of the superheater tubes.

Since steam influences the lubrication of cylinders and valves and, consequently, the selection of cylinder and valve oil, we must not overlook the conditions affecting the use of steam after it has left the engine, *i.e.,* as exhaust steam.

We will later analyze these conditions, first under "Exhaust Steam" and second under "Feed Water Treatment." The latter subject is of especial importance as the feed water frequently is taken from the condensed exhaust steam and the oil present in the exhaust steam may affect the quality of the feed water and cause boiler trouble.

Impurities in the Steam

Solid impurities in the steam are mainly of two kinds, namely: (1) Iron oxides (rust) from the boiler, superheater tubes, or from the steam line. (2) Salts and impurities in the water carried over from the boiler with the steam during periods of "priming."

These impurities when carried by the steam into the engine adhere and cling to the oil film all over the internal rubbing surfaces. The result is the formation of a dark-colored sludge or paste, which accumulates in the valves, valve ports and passages, the spaces between and behind the piston rings and on the piston faces.

In extreme cases the piston rings will be completely choked with deposits. They then become inflexible in their grooves and no longer perform their function of preventing leakage of steam from one side of the piston to the other.

The result is excessive wear of the piston rings and cylinder and heavy loss of power due to the increased friction and steam leakage past the piston. The valves and pistons groan, and various other indications of excessive friction characteristic of the different kinds of valve motion become apparent.

The washing effect of wet steam has a tendency to remove the deposits from the high-pressure cylinder and valves. Sometimes, in these cases, a liberal supply of cylinder oil or the use of a lighter bodied oil will give temporary relief.

With superheated steam, the deposits formed in the high-pressure valves, valve chambers and cylinders remain there and are baked into hard, carbonaceous deposits which are most objectionable and cause heavy wear. This is particularly true where a cylinder oil of very heavy viscosity is used.

A liberal oil feed will only accentuate this trouble, as the excess oil simply decomposes and forms more deposits. The use of a lighter bodied cylinder oil will frequently help to loosen the deposits and remove them from the high-pressure valves and cylinders.

In many cases where the direct method of lubrication has been in force, with resultant heavy carbonization, great improvements have been secured by introducing the atomization method of lubrication.

It is obvious that, where oil is introduced direct to the various frictional surfaces, time is required for it to spread. Therefore, more oil is required, and it is to this surplus oil that the impurities adhere.

Where the cylinder oil introduced is thoroughly atomized by the steam, it is spread to the best advantage over the internal surfaces and presents only a thin lubricating film to which the impurities may adhere. Better atomization and distribution of the cylinder oil result not only in greater economy but also in cleaner internal lubrication, *i.e.,* less deposits.

Where the steam is very clean and high-quality oils are used, carbonization seldom occurs.

If, however, the steam is dirty, the impurities in the steam will adhere to the oil film and, due to the high temperature, a layer of oil carbon will be formed by oxidization on top of the impurities. Later, a new layer of impurities will cover the layer of oil carbon, and a second layer of oil will produce more oil carbon, and so on.

Thus, an examination of a crust of carbonaceous matter will frequently be seen to consist of alternate layers of impurities and oil carbon.

There are cylinder oils on the market which have been especially made and are of such a char-

acter that they will produce practically clean lubrication notwithstanding dirty steam.

Where the feed water is treated chemically and a surplus of soda reaches the boiler, priming occurs. Even a small quantity of soda in the steam has a very deleterious effect on lubrication, as it dries up the oil film and a more liberal oil feed becomes necessary.

With superheated steam a greater feed of oil will only mean more trouble and the formation of carbonaceous deposits.

The best remedy is to make sure that the feed water softening plant is in good order and that the tendency of the boiler to prime is overcome or minimized by adhering to the proper water level, by keeping clean water in the boiler and by providing sufficient boiler capacity, so that the boilers are not overloaded.

A chemical analysis of deposits developed in a steam engine is always of service in tracing the cause of the deposit.

A very simple test that can easily be performed is to take a portion of the deposit and heat it on a metal plate. The oil will burn away, leaving a residue.

If the residue consists mainly of iron and rust this will indicate that rusty matters have been carried over to the engine or that wear is taking place.

If the residue consists of chalky matters of a light or yellowish-reddish color the indications point to priming of the boilers resulting in the boiler salts being carried over by the steam into the engine.

If the whole of the deposit burns away, it shows that the oil in use has produced oil carbon and that the oil was either of unsuitable quality, that it was used in excess quantity, or that it was not distributed in the best possible manner.

EXHAUST STEAM

Non-Condensing

The steam having done its work in the engine, passes out into the exhaust pipe (10) (Fig. 18) which may simply communicate with the atmosphere through the automatic relief valve (21) and pipe (22), or in other cases the exhaust steam may be used for heating purposes. In all such instances the engine is called a *non-condensing engine.*

Exhaust steam from auxiliary steam engines may pass through the heater (20) on its way to the atmosphere. The heat of the exhaust steam raises the temperature of the boiler feed water.

By raising the temperature of the boiler feed water, less fuel is required to convert the water into steam and boiler efficiency is increased.

Condensing

It is possible, however, to obtain much greater efficiency from the steam engine if the exhaust steam when leaving the engine is condensed.

The transformation of a large volume of the exhaust steam into a comparatively small volume of water creates a partial vacuum. The expansive force of the live steam acting each stroke on one side of the piston is thus made more effective through the lowering of the pressure against which the engine exhausts, *i.e.,* a partial vacuum.

There are two systems of condensation: the jet condensing and the surface condensing systems. The engine is called either a jet condensing engine or a surface condensing engine, according to the system employed.

Jet Condensing System (Fig. 18)

The exhaust steam enters the jet condenser (13) through the pipe (12); it meets on its entrance numerous jets of cold water coming through the water supply pipe (16) from the turbine-driven condensing pump (23).

The cold water cools and condenses the large volume of exhaust steam into a small volume of warm water which collects at the bottom of the condenser (13), thus forming a vacuum in the condenser. By means of a pump the water is taken from the condensing chamber and delivered through pipe (14) into the hotwell (15) from which a portion of the water may be taken away by the boiler feed pump (2) for boiler feed purposes.

The bulk of the water is either allowed to waste, or where only a limited supply of cooling water is available, is passed through a cooling tower (not shown) where it is cooled and used as condensing water over and over again.

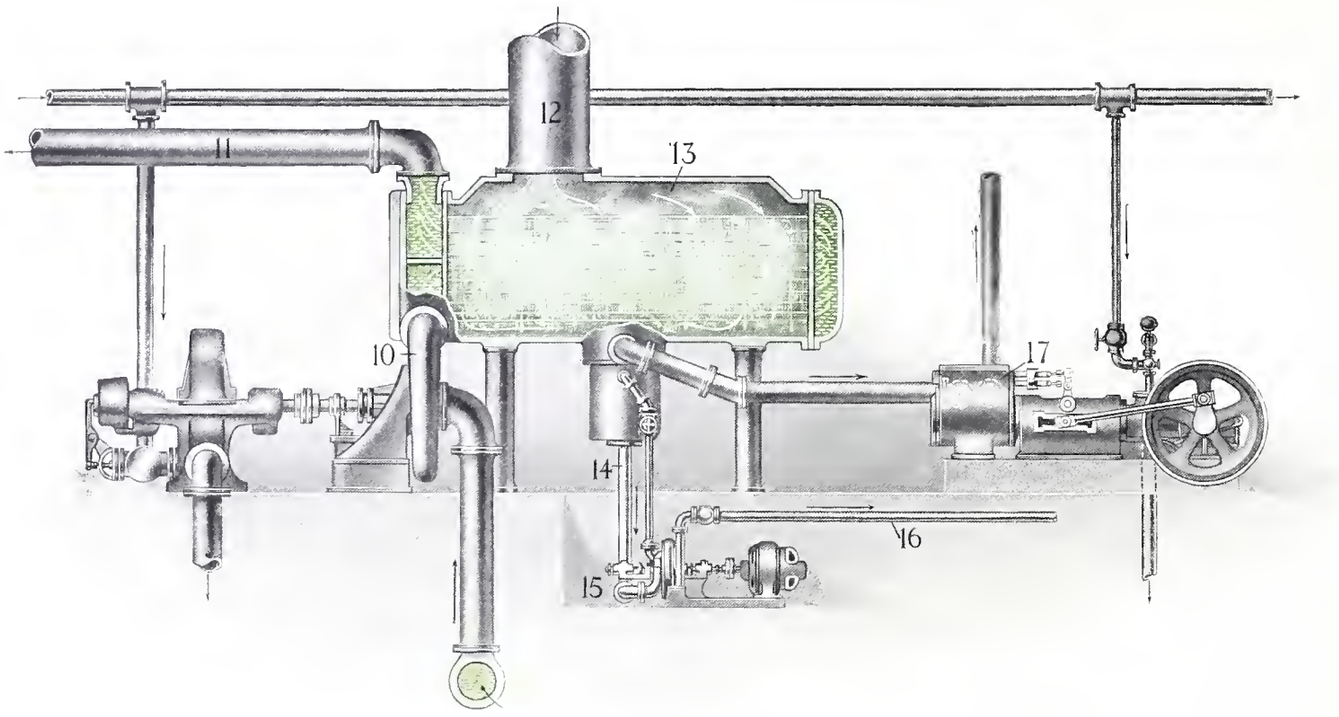

Fig. 19—Part Sectional View of Surface Condensing Plant

Surface Condensing System (Fig. 19)

Exhaust steam in this case is condensed by passing it through a large condensing chamber (13), in which are a great number of tubes through which cold water is passed.

The cooling water is supplied from a convenient outside source by means of a turbine-driven circulating pump (10). The cold water passes from one end of the condenser to the other end through the lower set of tubes and then is returned through the upper set of tubes from whence it leaves the condenser by pipe (11).

The exhaust steam is cooled and condensed, draining through pipe (14) into the wet pump (15) which pumps the hot water of condensation through pipe (16) into the hotwell (not shown). This water from the hotwell is delivered by the boiler feed pumps back into the boiler, where it is converted again into steam.

The dry vacuum pump (17) removes the air and non-condensable vapors from the condenser.

A high degree of vacuum is thus produced which would be impossible by rarefaction due to steam condensation alone.

OIL IN EXHAUST STEAM

A part of the oil used for lubricating the steam engine cylinders and valves will pass out with the exhaust steam and be present in one of two forms—*oil in suspension* or *oil in emulsion.*

Oil in Suspension

Oil in suspension (Fig. 20) consists of oil globules that are fairly easily removed from the steam by the exhaust steam oil separator. The globules of oil which are not extracted from the steam in the separator in the exhaust line will, in the case of condensing engines, mix with the condensed steam and pass to the hotwell. Here the greater portion will rise to the surface in the form of "float" oil which can be readily skimmed off.

The boiler feed pump should take its suction low down in the hotwell so as to minimize the danger of drawing in the float oil with the feed water.

A final safeguard may be provided in the form of feed water filters, the filter medium being sand, wood, wool or other material which will retain the globules of oil.

Oil in Emulsion

Oil in emulsion consists of very minute particles of water coated with an oil film. These particles are so small that they are carried along in the steam, and the exhaust steam oil separator will remove only a portion of them.

The greater portion of the oil in emulsion, therefore, mixes with the condensed steam, which assumes a milky appearance. The greater the

amount of oil, the milkier will be the appearance of the water. When only a small percentage of oil is present in emulsion, the water will be almost clear.

Whereas oil in suspension may be fairly easily removed in the hotwell or in the feed water filters, this is not true of oil in emulsion. The particles are so small that they will not rise to the surface in the hotwell and the filtering medium in the feed water filter cannot retain them.

Oil in suspension in the boiler rises to the surface of the water and can be easily removed through the scum cock.

Fig. 20—Sample of Oil in Suspension

Oil in emulsion combining with the boiler impurities, such as carbonates of lime or magnesia, rust, etc., coats the hot tubes or flues and the plates of the boiler thus retarding the flow of heat. The danger resulting from oil deposits is more pronounced in new boilers with clean tubes or flues than in used boilers protected by the formation of a certain amount of boiler scale.

EXTRACTION OF OIL

Exhaust Steam Oil Separator

Some exhaust steam oil separators consist of very large reservoirs, fitted with baffle plates, in which the exhaust steam loses its velocity, the oil and moisture separating mainly by gravitation.

Other exhaust steam oil separators are more compact and operate on the principle of splitting up the steam into many little flows with frequently changing direction. The oil is trapped by baffle plates, which are so designed that once the oil has become separated it cannot be picked up again by the steam, but gravitates to a reservoir in the bottom, from which it can be removed at intervals.

Chemical Treatment

Oil in emulsion may be removed from the feed water by producing a flocculent precipitate with the addition of certain chemicals (alumina-soda process). The large precipitated particles catch and absorb the minute particles of emulsified oil so that subsequent filtration easily removes the flocculent precipitate and with it the oil.

As a result, the water when it leaves the treating plant is transparent and practically free from oil. The treatment has the disadvantage, however, that certain chemicals are added to the feed water. This is objectionable as the chemicals may increase the tendency of the boiler to prime.

Electrical Treatment

Another method is the electrical treatment, by which the milky feed water containing the emulsified oil is passed through a tank containing two rows of iron plates. An electrical current is passed through the water from one set of plates to the other. The result is that the minute particles of emulsified oil coagulate and combine with iron oxide (rust) produced on the plates, forming a heavy deposit which can be easily removed by subsequent filtration.

By this method it is possible to remove practically every trace of oil from the feed water.

FEED WATER TREATMENT

Boiler feed water is always city supply water, river, lake, pond, or well water, and is pumped either direct to the boiler or is first passed through the heater (20) (Fig. 18).

Where the feed water is taken from rivers, care should be exercised in taking it from as clean a place as possible and to prevent impurities from entering the water; in rainy weather the rivers are swollen and muddy, and if dirty feed water is introduced into the boilers they are likely to prime and the impurities will be carried over into the engine with the steam and cause trouble.

Usually, feed water contains various kinds of salts in solution such as lime, magnesia, etc., which will produce boiler scale, greatly decreasing the efficiency of the boiler and impairing its steam-producing capacity.

Feed water which produces scale is called hard

water. The degree of hardness varies considerably, depending upon the character of the feed water.

By adding chemicals to hard feed water, some of the lime and other ingredients are precipitated and removed in the form of sludge. The remainder are transformed into such salts as will not produce scale inside the boiler.

In small plants a frequent practice is to introduce the chemicals into the hotwell or directly into the feed water on its way to the boiler, or even into the boiler itself. In such cases a great deal of sludge is produced which necessitates frequent "blowing down" of the boiler

The best method of adding the chemicals is to provide an independent feed water softening plant so that the water, after treatment, will reach the boiler in as purified a condition as possible. The sludge precipitated in the softening is easily removed by filtration.

All boilers are fitted with a scum cock to blow out surface scum and impurities, and a blow-off cock to blow off sludge from the bottom of the boiler.

Even if the feed water has been so treated that no scale is being formed in the boiler, it is obvious that, as steam evaporates away from the boiler, the water will become more and more concentrated with salts in solution. This increases the tendency of the boilers to prime. Therefore, in this case a certain amount of water should occasionally be blown out and replaced with fresh feed water.

Feed water, after treatment, is slightly alkaline; if it becomes excessively alkaline, the boilers will prime. The degree of alkalinity should, therefore, be kept as low as possible.

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